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Enlarged twice

THE MILKY WAY NEAR THE TAIL OF THE SCORPION

R. A. 17 hours 50 minutes; S. D. 35°. Exposure 3 hours; 6-inch portrait lens.

'ick Observatory E. E. BARNARD

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME V JANUARY 1897 NUMBER 1

ON THE SPECTROSCOPIC BINARY α^1 GEMINORUM.

By A. BÉLOPOLSKY.

MY first photographs of the spectrum of this star (mag. 3.4, or, according to O.Σ, 3.7) were obtained for April 7 and 11, 1894, with the two-prism spectrograph of the Pulkowa Observatory mounted on the 30-inch equatorial. The two velocities in the line of sight, which I derived from the measurements by Vogel's first method (the star belongs to the same class as Sirius), differed by an amount which greatly exceeded the probable error of observation.

As I then suspected that the stars α^1 and α^2 Geminorum had been observed on the two nights, and not α^1 alone, but had no opportunity at that time to repeat the observations, the question whether the different velocities were real or not had to remain undecided.

It was not until January of the present year that I was able to resume the investigation, and I then found that my conjecture that the star is a binary was confirmed by thirty-two spectrograms, obtained between January 1 and April 26. In this connection I may remark that the spectra of α^1 and α^2 Geminorum are so different that one cannot possibly be mistaken for the other.

The exposure to the star was one hour; in the middle of the exposure the comparison spectrum of hydrogen was photo-

graphed. The star spectrum contains, besides the very broad hydrogen lines, all the stronger lines of iron, a circumstance which increases the certainty of the measurements. Using all the available material in the most careful manner possible[1] I obtained a series of values for the velocity of the star in the line of sight, and these values, after reduction to the Sun, exhibited a periodical change having a period of about 2.9 or 3.0 days. A closer approximation to the period was obtained by a consideration of the times at which the observed velocities in the line of sight were nearly zero. Such times are:

Pulkowa Mean Time			Velocity
1896.	February	$24^d.418$	$+1^{km}.3$
	"	27 .367	−0 .9
	March	8 .363	+0 .9
	"	11 .321	+2 .7
	"	30 .350	+1 .7

Here it is necessary to take into account the fact that on February 24 and 27 and March 30 the velocities are increasing (changing from negative to positive values), and on March 8 and 11 decreasing. A short computation then gives for the actual times of zero velocity the following:

1896.	February	$24^d.399$ Pulkowa M. T.
	"	27 .379
	March	8 .375
	"	11 .358
	"	30 .326

Comparing those times which are separated by the shortest intervals (February 24 and 27, March 8 and 11) we obtain a period of 2.98 days; on the other hand, the period obtained from the dates February 24 and March 30, February 27 and March 30, is 2.91 days. I have used the latter value in computing the times of zero velocity, which are:

$$1896, \text{ February, } 27^d.34 \pm 2^d.91\, n,$$

where n is a whole number.

A provisional curve of velocities showed that the times of periastron passage occur $1^d.47$ later than the times of zero velocity.

[1] *Bull. Acad. St. Pétersburg*, December 1896.

In the following table are given, for each spectrogram obtained, the time at the middle of the exposure, the time of the nearest preceding periastron passage, the interval between this time and that of the observation, and finally the velocity reduced to the Sun.

LIST OF SPECTROGRAMS OF α¹ GEMINORUM.

Number	Date of Obs., 1896. Pulkowa M. T.	Periastron Passage, Pulkowa M. T.	Interval	Velocity relative to Sun
1	Jan. $1^d.43$	Dec. $29^d.70$	$2^d.73$	$-26^{km}.8$
2	20 .45	Jan. 19 .07	1 .38	+20 .6
3	Feb. 7 .43	Feb. 5 .53	1 .90	+22 .3
4	15 .45	14 .26	1 .19	+ 5 .6
5	19 .44	17 .17	2 .27	+18 .6
6	22 .42	20 .08	2 .34	+ 6 .2
7	23 .42	22 .99	0 .43	−33 .7
8	24 .42	22 .99	1 .43	+ 1 .3
9	25 .33	22 .99	2 .34	+16 .0
10	26 .36	25 .90	0 .46	−45 .4
11	27 .37	25 .90	1 .47	− 0 .9
12	Mar. 8 .36	Mar. 5 .63	2 .73	+ 0 .9
13	9 .32	8 .54	0 .78	−37 .9
14	11 .32	8 .54	2 .78	+ 2 .7
15	14 .38	14 .36	0 .02	− 9 .5
16	16 .33	14 .36	1 .97	+26 .1
17	17 .35	17 .27	0 .08	−38 .1
18	24 .38	23 .09	1 .29	−25 .7
19	30 .35	28 .91	1 .44	+ 1 .7
20	31 .36	28 .91	2 .45	+28 .5
21	Apr. 1 .36	31 .82	0 .54	−45 .0
22	3 .36	31 .82	2 .54	+22 .6
23	7 .36	Apr. 6 .64	0 .72	−40 .1
24	8 .36	6 .64	1 .72	+ 8 .6
25	11 .34	9 .55	1 .79	+ 7 .3
26	14 .35	12 .46	1 .89	+15 .9
27	17 .45	15 .37	2 .08	+17 .5
28	19 .39	18 .28	1 .11	−31 .3
29	20 .39	18 .28	2 .11	+20 .3
30	22 .41	21 .19	1 .22	−16 .5
31	24 .45	24 .10	0 .35	−47 .6
32	26 .40	24 .10	2 .30	+34 .7

With these values I constructed the curve of velocity, by taking the figures in the fourth column for abscissæ and those in the last column for ordinates. The scale was chosen so that 2 units = 1 geographical mile[1] (= 7.42 kilometers), 10 units

[1] In accordance with the practice of this JOURNAL (3, 1–3, 1896) the German geographical miles used by Herr Bélopolsky have been changed to kilometers, except

$=1$ day. It is at once apparent that the curve can be drawn either through the points No. 7, 1, 2, 4, 3, 5, 6, 9, or through all the remaining twenty-four points. A single curve cannot be drawn at once which will satisfy all the observations. Leaving the eight points out of consideration, and drawing through the others a curve which fulfils certain known conditions,[*] we obtain the following results:

Motion of the system relative to Sun $= - 1^{g.m}.06 = - 7^{km}.9$

Area bounded by curve, maximum ordinate and axis of abscissæ; $z_1 = + 1010$ units (diminishing velocity), and $z_2 = - 1575$ units (increasing velocities) $z_1 - z_2 = 2585 \pm 7$.

Greatest positive ordinate, $A = 10.46 = 5^{g.m}.23 = 38^{km}.8$.

Greatest negative ordinate, $B = 10.94 = 5^{g.m}.47 = 40^{km}.6$.

Let u_1, $u_2 =$ the longitudes of those points on the orbit for which the velocity in the line of sight $= 0$,

$\omega =$ longitude of the periastron,

$e =$ eccentricity,

$\left(\frac{dz}{dt}\right) =$ velocity in the line of sight at the time of periastron passage,

$T =$ time of periastron passage,

$2a =$ major axis,

$i =$ inclination,

$\mu =$ mean motion,

$U =$ period, so that $\mu = \frac{2\pi}{U}$.

The following formulæ are used in the computation:

$$\sin u^1 = \frac{2\sqrt{AB}}{A+B}, \quad \cos u_1 = \frac{A-B}{A+B},$$

$$e \sin \omega = \sin u_1 \frac{z_2 + z_1}{z_2 - z_1}, \quad e \cos \omega = - \cos u_1,$$

$$\left(\frac{dz}{dt}\right) = \frac{A+B}{2} (1 + e) \cos \omega,$$

T is the abscissa corresponding to $\left(\frac{dz}{dt}\right)$.

$$a \sin i = 43{,}200 \; \frac{A+B}{\mu} \sqrt{1-e^2}.$$

in parts of the paper relating to the graphical construction, where a change of units did not seem to be desirable.—EDS.

[*] R. LEHMANN-FILHÉS, *A. N.*, 3242, 136, 16–30.

The ephemeris was computed by means of the following formulæ:

$$\frac{dz}{dt} = \frac{A+B}{2}\cos u + \frac{A-B}{2}.$$

$$\mu\,(t-T) = E - e\sin E.$$

$$\tan\frac{u-\omega}{2} = \sqrt{\frac{1+e}{1-e}}\tan\frac{E}{2}.$$

The values obtained are:

$$A + B = 21.40 \qquad z_2 + z_1 = -\ 565$$
$$A - B = -\ 0.48 \qquad z_2 - z_1 = -\ 2585$$
$$2\sqrt{AB} = 21.40$$
$$u_1 = 88^\circ.7 \qquad \left(\frac{dz}{dt}\right) = -\ 0^{g.m}.7 = -\ 5^{km}.2$$
$$\omega = 96^\circ.0 \qquad T = +\ 0.01 \text{ day.}$$
$$e = 0.22 \qquad a\sin i = 837{,}000 = 418{,}500^{g.m} = 3{,}105{,}000^{km}.$$

The periastron passage occurs on

1896, February 28.82 $\pm$ 2.91n.

If, with these elements, we compute the motion in the line of sight at the times of observation, we obtain the following table:

Number	u	$\frac{dz}{dt}$	Curve	Obs. + $7^{km}.9$
20	13°.8	$+37^{km}.6$	$+39^{km}.0$	$+36^{km}.4$
22	27 .0	+34 .5	+37 .5	+30 .5
12	59 .2	+19 .3	+22 .7	+ 8 .8
14	68 .6	+13 .7	+15 .3	+10 .5
15	98 .0	− 6 .4	− 8 .8	− 1 .6
17	110 .0	−14 .5	−18 .8	−30 .3
31	159 .0	−37 .9	−38 .9	−39 .7
21	186 .6	−40 .3	−40 .0	−37 .1
23	208 .4	−35 .8	−36 .7	−32 .4
13	215 .2	−33 .5	−35 .2	−30 .1
28	246 .6	−16 .6	−19 .2	−23 .4
30	255 .8	−10 .6	−12 .2	− 8 .6
18	261 .6	− 6 .7	− 8 .0	−17 .9
19	274 .0	+ 1 .9	+ 2 .5	+ 9 .6
24	297 .0	+17 .1	+16 .8	+16 .5
25	303 .0	+20 .7	+20 .9	+15 .1
26	311 .9	+25 .6	+26 .3	+23 .7
16	319 .2	+29 .2	+30 .1	+34 .0
27	329 .8	+33 .4	+34 .6	+25 .4
29	332 .8	+34 .4	+35 .3	+28 .2
32	354 .2	+38 .6	+39 .0	+42 .5

The points which were not used seem to form a group by themselves, and not to correspond at all to this curve. Only the points 8, 10, and 11 lie near it, while 3 has such a position that the curve is occasionally satisfied.

The cause of this discrepancy is probably that (as has already been remarked) the period 2.91 days cannot be used throughout the whole time covered by the observations. Hence a correction must be applied to the abscissæ of the points 7, 2, 4, 3, 5, 6, 9, and 1, and then a new curve drawn through these and the points previously considered.

The correction desired can be obtained graphically from the first curve. It is $0^d.32$. The corrected abscissæ are therefore :

1.	$3^d.05$	7.	$0^d.75$
2.	1 .70	8.	1 .75
3.	2 .22	9.	2 .66
4.	1 .51	10.	0 .78
5.	2 .59	11.	1 .79
6.	2 .66		

With these values we obtain:

Motion of system relative to Sun $= -1^{g.m}.40 = -10^{km}.4$

$$z_1 = +951 \quad A = 10.3 = 5^{g.m}.15 = 38^{km}.2$$

$$z_2 = -1470 \quad B = 10.00 = 5^{g.m}.00 = 37^{km}.1$$

$$u_1 = 90^\circ.9 \quad \left(\frac{ds}{dt}\right) = -0^{g.m}.8 = -5^{km}.9$$

$$\omega = 94^\circ.0 \quad T = -0^d.07$$

$$e = 0.21 \quad a \sin i = 794{,}000 = 397{,}000^{g.m} = 2{,}946{,}000^{km}.$$

The epoch of periastron passage is

1896, February, $27^d.74 \pm 2.91n$.

The following velocities have been computed with the aid of these elements :

No.	u	$\frac{ds}{dt}$	Curve	Obs. $+10^{km}.4$
1	$131^\circ.8$	$-25^{km}.7$	$-26^{km}.8$	$-16^{km}.4$
2	300 .4	+18 .5	+17 .8	+31 .0
3	353 .2	+36 .9	+37 .5	+32 .7
4	284 .4	+ 8 .8	+ 7 .8	+16 .0

No.	u	$\frac{ds}{dt}$	Curve	Obs. + $10^{km}.4$
5	47 .3	+25 .1	+28 .9	+29 .0
6	59 .6	+18 .5	+20 .8	+16 .5
7	226 .4	−26 .6	−30 .1	−23 .3
8	305 .0	+21 .1	+20 .0	+11 .7
9	59 .6	+18 .5	+21 .5	+26 .4
10	220 .6	−29 .2	−28 .9	−35 .0
11	308 .4	+22 .8	+22 .3	+ 9 .5
12	72 .8	+10 .6	+14 .1	+11 .3
13	220 .6	−29 .2	−28 .9	−27 .5
14	82 .4	+ 4 .4	+ 5 .9	+13 .1
15	111 .4	−14 .3	−16 .3	+ 0 .9
16	325 .4	+30 .5	+30 .1	+36 .5
17	123 .0	−21 .1	−24 .1	−27 .8
18	266 .2	− 3 .1	− 3 .7	−15 .4
19	278 .6	+ 5 .0	+ 5 .2	+12 .4
20	24 .8	+33 .6	+36 .4	+38 .9
21	193 .8	−37 .2	−36 .0	−34 .6
22	38 .8	+28 .8	+31 .5	+33 .0
23	214 .4	−31 .8	−31 .2	−29 .8
24	302 .6	+19 .7	+19 .3	+19 .0
25	308 .4	+22 .8	+21 .9	+17 .7
26	317 .8	+27 .4	+26 .7	+26 .3
27	337 .0	+34 .1	+34 .1	+27 .9
28	251 .0	−12 .8	−13 .0	−20 .9
29	340 .4	+34 .9	+35 .2	+30 7
30	260 .4	− 6 .8	− 6 .7	− 6 .1
31	168 .2	−37 .5	−36 .7	−37 .2
32	3 .0	+37 .1	+38 .2	+45 .0

The discrepancy which is exhibited by the velocities obtained in January and February when compared with all the others, as well as the different values of the period which they yield, cannot be explained with certainty at present. However, I should not wish to leave unmentioned a certain possible cause, which is a rapid motion of the line of apsides in the direction of the orbital motion of the star. Such a case is known to be possible when a disturbing force exists, due to a flattening of the central body, and the probability of this explanation is increased by Dunér's analogous investigation of the variable star Y Cygni, the unequal periods of which are explained by the motion of the line of apsides. It is hardly necessary to point out that in this case the available data are hardly sufficient to determine the amount of the motion.

PULKOWA, November 1896.

ON AN AUTOMATIC ARRANGEMENT FOR GIVING BREADTH TO STELLAR SPECTRA ON A PHOTOGRAPHIC PLATE.

By WILLIAM HUGGINS.

IN my original paper on the "Photographic Spectra of Stars" (*Phil. Trans.*, 171, Part II, p. 672, 1880) I point out that the necessary breadth may be given to a photographic spectrum, without the use of a cylindrical lens, by simply causing the star's image to travel slowly in the direction of the length of the slit. At present it is usual, the length of the slit being fixed in the direction of the star's motion, by making the rate of the clock slightly fast, to cause the star to travel slowly along the slit, and when it has passed through a distance corresponding to the breadth which is desired for the photographic spectrum, by means of the slow-motion arrangements of the equatorial, to bring the star back to its first position; and in this way, by a sufficient number of runs of a fixed length, to make up the time of exposure which may be required. Without the assistance of an efficient electric control on the speed of the clock, this periodical bringing back of the telescope during a long exposure becomes very irksome, and brings in a serious loss of time. Even if the telescope is provided with a modern electric clock control, the method of successive runs by hand is troublesome and fatiguing, with the very long exposure so often necessary.

A few years ago an automatic arrangement suggested itself to me by which any desired amount of breadth could be given to photographic spectra with great precision and without interference by hand, except so far as may be required by change of refraction or from error of the clock rate. In this plan of working the clock must not be fast, but accurately adjusted to the motion of the stars, so that the star's image would remain fixed at any point of the slit at which it was put. Then, by means of an adjustable eccentric cam, introduced between the

clock and the driving screw, the stellar image is made to oscillate backwards and forwards about its mean position to any extent that may be desired. It is necessary to have the means of adjusting the amount of eccentricity to the breadth of spectrum desirable with the spectroscope which is in use; and also the means of removing, at pleasure, the eccentric motion when it is not required.

I took some spectra by this method some years ago, but the wheel which I then employed could not be made sufficiently eccentric. Recently I have had constructed a very simple eccentric arrangement which fulfils these conditions.

The clock-motion on its way to the driving-screw passes through two wheels gearing into each other, of the same diameter and of the same number of teeth. One of the wheels is provided with a cam by which the axis can be moved outside the center of figure of the wheel. This is effected by moving a small lever on the front of the wheel, which can then be fixed by a clamp in a position corresponding to any desired amount of eccentricity, or breadth of spectrum, within the range furnished by the cam. It is only necessary to bring back the lever to its first position, and to screw up the clamp, to make the wheel concentric, when the clock-motion will be transmitted to the driving screw without alteration of rate.

It is obvious that when the wheel is made eccentric, the star will slowly travel to and fro about its mean position. The time required to make a complete revolution in my instrument is about two minutes.

It should be pointed out that as the teeth of the eccentric wheel alternately approach and recede from the other wheel during each revolution, the teeth of both wheels should be long and suitably shaped, so as to allow of considerable interpenetration when the center of figure of the eccentric wheel is on the side of the axis which is nearer to the other wheel.

When such an eccentric wheel is employed the exposure increases towards the ends of the runs, that is, towards the two edges of the spectrum. If the unequal photographic action be

considered an objection, some other mechanical arrangement may be substituted for the eccentric wheel. For instance, a suitable automatic action upon the electric control of the clock, or upon a "mouse wheel." A simpler plan is to have both wheels of the pair concentric, but one of them furnished on one-half of its circumference with one tooth, or at most two teeth more, and on the other half with the same number of teeth fewer than the number required to transmit the clock-motion without alteration. The difference in the number of teeth would be too small to prevent good gearing of the wheels; and in this case the exposure would be uniform throughout the runs, and the photographs uniform throughout the breadth of the spectrum.

By the use of an automatic mechanical arrangement not only will the personal fatigue of the observer be greatly lessened, but, what is of no little importance in a variable climate, the necessary time of exposure will be reduced, for every moment of the exposure will tell upon the plate, since there will come in no interruptions of photographic action, through any want of immediate and accurate bringing back of the star at the end of each run, as can scarcely fail to be the case when it has to be done by hand.

LONDON, November 23, 1896.

PLATE II.

N

E

W

S

Enlarged twice

THE CLUSTER MESSIER 35

R. A. 6 hours 3 minutes; N. D. 24° 20′. Exposure 2 hours 10 minutes; 6-inch portrait lens

-k Observatory Feb. 1, 1894. E. E. BARNARD

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XVI.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3259.720		0	3265.454	Co	0 N
3259.834		0	3265.678		2
3259.977		0000 N	3265.762	Fe	4
3260.110	Cr, Fe	4	3265.822		00
3260.266		000	3266.016	V	1
3260.386 s	Mn, Ti- Fe	5 d?	3266.102		000
3260.593		0000	3266.275		000
3260.673		00	3266.362		000
3260.813		000 N	3266.561		00 Nt?
3260.950	Co	1	3266.798		3 N
3261.079		0000 N	3267.072		1
3261.186		00 N d?	3267.184		1
3261.319		0000 N	3267.328		00
3261.460	Fe	2	3267.391		000
3261.705	Ti	3	3267.561		00
3261.760		4	3267.661		0000 N
3261.938		00	3267.834 s	V	6
3262.142	Fe	2	3267.910	Mn	0000
3262.409	Fe- Sn	3	3268.186		1
3262.558		0000	3268.366	Fe	3
3262.838		0000 N	3268.468		0000
3263.023		3	3268.558		0000
3263.194		1	3268.644		00
3263.254		0000	3268.847	Mn	0000
3263.355	V, Co	0	3268.983		000
3263.491	Fe	4	3269.098		0
3263.587		0000	3269.207		000
3263.813	Ti	4	3269.355	Fe	1
3263.960		0 N	3269.462	Fe	00
3264.097		0	3269.555		0
3264.187		0	3269.627		0
3264.307		00 N	3269.747	Zr	0000 N
3264.405		1	3269.890		1
3264.528	Mo?	0	3270.033		000
3264.646	Fe	4	3270.089	Fe	2
3264.833	Mn	2	3270.265	-,Co	1 N
3264.906	Co	2	3270.473	Mn	00
3264.983		00	3270.656		0000 N
3265.176	Fe,-	3 d?	3270.794	Ti?	0
3265.310		0000	3270.872		0000 N

Wave-length	Substance	Intensity and Character	Wave length	Substance	Intensity and Character
3271.129	Fe	6	3278.221		000 N
3271.266	Ni, Co, Zr, V	5	3278.420	Ti	5
3271.436		0000	3278.574		0000
3271.536		0000	3278.687	Mn	1
3271.621	Fe	1	3278.867	Fe	3
3271.791	Ti, Fe	6d?	3278.974		00
3271.918	Co	0	3279.060	Ti	4
3272.085		0000 N	3279.279		1
3272.217	Ti	5	3279.400	Zr, Co	2
3272.367	Zr	2	3279.574		0000
3272.558		0000 Nd?	3279.644		0000
3272.729		1	3279.784		0
3272.855		0	3279.872	Fe	1
3272.971		0000 N	3279.973	V	1
3273.175	Mn-Zr	2	3280.120	Ti	2
3273.311		0000	3280.256		000 N
3273.477		000	3280.392	Fe	4
3273.606		1 N	3280.493		0000 N
3273.758		0	3280.623		0000 N
3273.844		0000	3280.806	Ag	0
3273.970		0000 N	3280.900	Mn	1
3274.096 s	Cu	10	3281.100		0000Nd?
3274.350		1	3281.250		0 N
3274.575	Fe	3	3281.429	Fe	5
3274.677		0000	3281.652		0000
3274.800		0	3281.725		0000
3274.907		0000	3281.841		2
3275.033		1	3281.993	Ni	2 d?
3275.149		0000	3282.122		000
3275.276		0000	3282.372		00
3275.353		0000	3282.459	Ti, Zn	5
3275.423	Ti	3	3282.572		0
3275.529		0000	3282.665	V	1
3275.603		0000	3282.830	Ni	2
3275.716		000	3282.962	Ni	2
3275.809		1	3283.029	Fe	2
3275.969		0 N	3283.179		000
3276.103		000	3283.286		00
3276.259	V	5 d?	3283.332		00
3276.386		00	3283.458	Co	0
3276.594	Co, Fe	3	3283.576	Co,-	2
3276.741		1	3283.680	Fe	1
3276.905	Ti	3	3283.812		0000
3277.124	Ti	2	3283.929		00 N
3277.225		0000	3284.059		00
3277.315		0	3284.116		00
3277.482	Co-Fe	7 d?	3284.256		0000 N
3277.795	Co	0 N	3284.366		0000
3277.848		0 N	3284.489		0000
3277.997		0 N	3284.559	Ni	1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3284.648		0	3290.375		00
3284.723	Fe	2	3290.475		0000
3284.847	Zr	1	3290.602		00
3284.968		0000	3290.642		0 N
3285.148		0 N	3290.765		000
3285.324		1	3290.842	Fe	2
3285.421		0	3291.119	Fe	4
3285.547	Fe	2	3291.261		0 N
3285.678		00	3291.411		0900
3285.828		0000	3291.557		00
3285.908		0000	3291.671		000
3286.034	Fe?, Ti?	000 N	3291.824	Fe	00
3286.164		2	3291.897		1
3286.197		0	3292.151 } s	Fe	4
3286.310		0000	3292.206 }	Ti, Co	3
3286.384		000	3292.337		0000 N
3286.494		0000	3292.451		0
3286.580		1	3292.636		0
3286.667		00	3292.728	Fe	4
3286.784		0	3292.870		0000 N
3286.898	Fe	7 N	3292.996	Mn?	000
3286.980		0 N	3293.053		00
3287.086	Ni	3	3293.276	Fe, Co	2
3287.224	Fe	2	3293.350		0000
3287.347	Co	2	3293.605		00
3287.460	Zr?	000	3293.800	Fe	1
3287.560		000	3293.900		00
3287.597		000	3293.989	Co?	000 N
3287.709		0000	3294.125		0000 N
3287.793 s	Ti	5	3294.235		0000 N
3287.863		0000	3294.325		000 N
3287.986		0000 N	3294.462		0000 N
3288.175		0	3294.569		0000 N
3288.281	Ti	3	3294.682		0000
3288.453	Fe	00 N	3294.749	Co	00
3288.561	Ti	2	3294.849		000
3288.705	Ti	2	3294.949		00 N
3288.801	Fe	1	3295.069	Ti	0
3288.939	Zr	0	3295.149		0000
3289.103	Fe	2	3295.243		0
3289.153		0	3295.375		1
3289.272		0000	3295.562		2
3289.372		0000	3295.732		000
3289.498		4	3295.762		0000
3289.568	V	3	3295.951 s	Fe, Mn	6
3289.705		0000 N	3296.168	Mn?	00
3289.875		0000	3296.388		1 N
3289.988		000	3296.504	Zr?	000 N
3290.035		000	3296.602	Fe	2
3290.238		0000 N	3296.721		0000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3296.948		1	3302.895		0000
3297.014	Mn	1	3302.990		3
3297.194		0 N	3303.109 s	Na	5
3297.301	Co	0	3303.248	La	000 Nd?
3297.381		0	[1] 3303.398	Mn	00 N
3297.511		000	[1] 3303.601 } s		3
3297.644		000	3303.698 } s	Fe	2
3297.720		000	3303.908		000
3297.793		000	3304.022		0000 N
3297.963		0 N	3304.263		000
3298.009		1	3304.375	Mo?	1
3298.140		0000	3304.492		0
3298.268	Fe, V, Di	5	3304.577		000
3298.361	Mn	000	3304.611		000
3298.451		0000	3304.719		00
3298.545		0000	3304.881		00 N
3298.685		1	3305.001	Mn	00
3298.818	Co	2	3305.089	Ni	1
3298.869	V	3	3305.194		000
3298.995		0000	3305.283	Co-Zr	2
3299.211		1	3305.354		000
3299.305		0000	3305.434		0000
3299.477		0000	3305.541		0000
3299.564	Ti	2	3305.604		0000
3299.652	Mn	0 Nd?	3305.754		000 N
3299.804		0	3305.877	Co	0
3299.905		0	3305.991		2
3300.017		000	3306.105 s	Fe	4 N
3300.204		0000 N	3306.221		2 N
3300.297		00 N	3306.296		0000
3300.444		0000 Nd?	3306.412 } s	Zr	2
3300.617		000	3306.506 } s	Fe	4
3300.687		0000 N	3306.623	Co	1
3300.802		000	3306.726		1
3300.944		0000	3306.830		000
3301.039		000	3306.903		0000
3301.143		0000 N	3307.010	Ti	00
3301.263		0000 N	3307.114	Mn	1
3301.352	Fe	1	3307.165	Fe	2
3301.552	Fe	0	3307.280	Co	1
3301.706		0000	3307.374	Fe	1
3301.808	Ti, Sr	1	3307.473		0000
3301.909		0000	3307.636	Sr?	000 N
3301.996		0000	3307.845	Fe	4
3302.055	Fe	0	3308.035		00 N
3302.232	Ti, Pd	4	3308.239		0 N
3302.289		0000 N	3308.405		0000
3302.443		0000 N	3308.527	Ti	0
3302.510 s	Na	6	3308.619	Co	00
3302.720	Zn	1	3308.749		000

[1] A zinc line comes between these two.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3308.888 } s	Mn	2	3314.476		000 N
3308.947 } s		5	3314.574	Ti, Fe, Mn	3 N
3309.065	Co, Ti	0000 N	3314.663	Ti	2
3309.159		0000	3314.742		000 N
3309.212		0000	3314.876	Fe	4
3309.325		0000 N	3314.995	Mn	0
3309.452		0000 N	3315.178	Co	000 N
3309.558	Ni	0	3315.303		0
3309.658	Ti,-	2 N	3315.385		0000
3309.851	Ti	00 N	3315.457	Ti	3
3309.974		0000	3315.548		0
3310.031		0000	3315.685		0000 N
3310.158		000	3315.807	Ni	7 d?
3310.248		0000	3316.081		0000
3310.338	Ni	2	3316.128		0000
3310.472	Fe	3	3316.325		000 Nd?
3310.626	Fe	2	3316.467		00
3310.777		1 N	3316.561	Mn	0
3310.996		0	3316.615		0000
3311.041		000	3316.698	Mn	00
3311.051		0000	3316.778		00
3311.238		0	3316.871		00
3311.343		00	3316.980		0
3311.477		000	3317.034		0000
3311.587		00	3317.174		00
3311.727		0000	3317.262	Fe	2
3311.843		000	3317.393	Mn	1
3312.023		0	3317.514		0
3312.063	Mn	2	3317.720		0
3312.187		0000	3317.830		0000
3312.325	Fe-Co	3 d?	3317.960		0000
3312.453	Co	2	3318.160 s	Ti	6
3312.563		00	3318.339		000
3312.729		1	3318.496	Ti-Co	1 Nd?
3312.827	Ti, Fe	2	3318.645	Zr	00
3312.970	Co	000	3318.741		000 N
3313.053		000	3318.895		00
3313.137	Ni	1	3319.035		0000Nd?
3313.206	Co	000	3319.172	Zr	0
3313.301	Mn	00	3319.207		1
3313.432		0000 N	3319.298	Co	00
3313.562	Mn	00	3319.387	Fe	2
3313.676		000 N	3319.491		000
3313.774		1	3319.619	Co	1
3313.853		0	3319.673		0
3313.929		0000	3319.815		0000
3314.042		00 N	3319.953	Co	0
3314.124		1	3320.032		0
3314.214	Co	1	3320.161		0000
3314.334	Mn	0	3320.258		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3320.391	Ni	7	3326.335		00
3320.508		0000	3326.432		000
3320.621		0000	3326.553		0
3320.783	Mn, Fe	2	3326.727		0 N
3320.907	Fe, Ni	1	3326.825	Co	1
3321.044		0000	3326.907[1]	Ti	5
3321.177	Be?	0000 N	3326.998[1]		3
3321.324		000	3327.127	Co	1
3321.366		0	3327.297		00
3321.494		0000	3327.424		0000
3321.550	Be?	000	3327.533	Ni	2
3321.667		00	3327.633	Fe	1
3321.715	Ti	00	3327.757		000
3321.836	Ti,	4	3327.861		0000 N
3322.047		000 N	3328.016	Di?	2
3322.190		0000	3328.101		0
3322.331	Co	1 Nd?	3328.341	Co	00
3322.454	Ni	3	3328.487		2
3322.610	Fe	2	3328.605		0
3322.784		00	3328.713		0000
3322.833		00	3328.849	Ni	1
3323.003		1	3328.933		0000
3323.056[1]	Ti	5	3329.000	Fe	3
3323.116[1]		3	3329.186	Cr, Fe	1
3323.213		1	3329.233		000
3323.256		00	3329.338		0000
3323.426		0000	3329.435		0000 N
3323.524		1	3329.568[1]	Ti, Co	5
3323.669		0	3329.648[1]		3
3323.881	Fe	3	3329.762	Fe	0000 N
3324.049		000	3329.902		00
3324.129		0	3329.982		000
3324.201		4 N	3330.044	Mg	3
3324.280		0	3330.102		2
3324.494	Fe	1	3330.212	Sr?	000
3324.674	Fe	3	3330.364		0
3324.808		0	3330.438		1
3324.921		1	3330.565		0000 N
3325.142		0	3330.645		000
3325.168		0000	3330.745	Sn?	000
3325.288		0000	3330.802	Mn	00
3325.381	Co	1	3330.914		000
3325.462		000	3331.056		1 N
3325.609	Fe	3	3331.194		000 N
3325.712		000	3331.384		00 N
3325.820		0000	3331.527		000
3325.886		0000	3331.747[1]	Fe	2
3326.028		000	3331.915	Fe	2
3326.105		0000	3332.061		000 N
3326.212		0000	3332.184		0

[1] See note to 3335.192, 3335.350, etc.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3332.240	Ti	3	3338.054 [1]		0
3332.326	Mg	3	3338.141		0000
3332.421		000 N	3338.247		0
3332.481		00	3338.368		000
3332.707		0000 N	3338.478		000
3332.850		0000	3338.561		000
3332.965		0	3338.651	Co	00
3333.026		0000	3338.759	Fe	2
3333.160		000	3338.905		0
3333.250		0	3338.944		0000
3333.353		000 N	3339.051		0000 N
3333.526	Co	2	3339.180	Ni?	1
3333.728		1	3339.333	Fe	2
3333.854		0	3339.438		000 N
3333.953		000	3339.577		000 N
3334.046		000	3339.713	Fe	1
3334.116		000	3339.818		1
3334.266	Co	4	3339.932	Co, Cr	3
3334.356	Fe	1	3240.011		1
3334.406	Zr?	1	3340.173		000 N
3334.613		0	3340.310		0000 N
3334.753	Zr	0	3340.464 [1]	Ti	3
3334.846		0	3340.523 [1]		2
3334.933		0000 N	3340.702	Fe	2
3335.065		000 N	3340.823		00 N
3335.192		0000 N	3340.957		0000 N
3335.299 [1]	Ti	4	3341.027		1
3335.350 [1]		2	3341.137		0000
3335.439		1	3341.300		0000 N
3335.553		1 N	3341.417		0000
3335.666		2 N d?	3341.480	Co	00
3335.859		1	3341.583		0000
3335.915	Fe	2	3341.690		·0000
3335.979		000	3341.820		000
3336.054		0	3341.967 [1]	Ti	4
3336.259		0	3342.062 [1]	Fe,-	4
3336.391	Fe	2	3342.280		0
3336.477	Cr	2	3342.358	Fe, Ti	3
3336.635		00 N	3342.442	Fe	3
3336.679		00	3342.506		0000
3336.820	Mg	8 N	3342.606		0000
3336.962		0 N	3342.717	Cr	3
3337.098		0	3342.829	Ti	00
3337.138		1	3342.892	Co	00
3337.319	Co	1 N	3343.032		00
3337.471		0000	3343.156		00
3337.524		000	3343.366		0
3337.630	La	0	3343.479		00
3337.803	Fe	3	3343.656		000 N
3337.984 [1]	Ti	2	3343.804	Mn	1

[1] There are several cases like this where there is a close double, one line at least belonging to Ti. It is not certain in such cases that both are not Ti lines. Possibly the second may be Ti and not the first. The notes do not yet settle these cases, except 3314.573 and 3314.663, when both lines belong to Ti.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3343.908	Ti	4	3349.965		0000
3344.036		0000 N	3350.080		000 N
3344.215		000 N	3350.214		000 N
3344.315		00	3350.347		2
3344.521		0000 N	3350.429		1
3344.655	La	2	3350.512		1
3344.721		0000	3350.545	Di?	1
3344.831		0000 N	3350.648	Ti	2
3344.924	Zr	0	3350.985		000
3345.015		000	3351.089		000
3345.068		2	3351.201		00
3345.156	Zn	2	3351.289		0000
3345.298		0000 N	3351.379		0000
3345.495	Mn	00	3351.472		0000
3345.618		000	3351.551		0000
3345.715	Zn	1	3351.658	Co-Fe	2
3345.761		00	3351.745	Cr	0
3345.835		00	3351.884 s	Fe	1
3345.955		000 N	3352.101	Cr	0
3346.047		000 N	3352.198	Ti	2
3346.154	Cr, Zn	0 N	3352.318		0000 N
3346.284		00	3352.578		000 N
3346.414		00	3352.771		00 N
3346.557		0	3352.908		000
3346.734		0000 N	3352.958		000
3346.860 [1]	Cr	3	3353.065	Ti, Fe	1
3346.904 [1]	Ti	2	3353.262		2
3347.066	Co	2	3353.402	Fe	1
3347.157		0000	3353.538		000 N
3347.267		0000 N	3353.661		0000 N
3347.450		000	3353.768	Zr	00 N
3347.507		000	3353.875		4
3347.638		0	3354.057		000 N
3347.760		00 N	3354.199	Fe	2
3347.970 s	Cr	3	3354.350	Co	00 N
3348.072 s	Fe	3	3354.523	Co, Zr	3
3348.254	Co	1	3354.670		00
3348.370		0000 N	3354.778	Ti	3
3348.520		0000 N	3355.023		00 N
3348.673		000	3355.197		0000 N
3348.820		000	3355.363	Fe	4
3349.043	Ti	4	3355.497		0000 N
3349.135	Ti, Cr	3	3355.661	Mn	0
3349.212	Ti	2	3355.797		0000 N
3349.399		00	3355.957		000 N
3349.519	Cr	2	3356.080		000
3349.597	Ti	7	3356.231 s	Zr	1
3349.695		00	3356.370		000 Nd?
3349.785		00	3356.462		2
3349.874		0	3356.548	Fe	2

[1] See note to 3335.299, etc.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3356.676	Co	000 N	3362.402		2 d?
3356.821	Fe	2	3362.528		0
3356.976		000	3362.727		0000
3357.092		0000	3362.782		1
3357.256		000 N	3362.936	Co	4 Nd?
3357.412	Zr	2	3363.107		0
3357.537		1	3363.298		0000 N
3357.703		0	3363.442	Co	0 d?
3357.816		0000	3363.542		1
3357.874		0	3363.750	Ni	1
3357.959		00	3363.854		1
3358.076		0000	3363.955	Co	0
3358.182		1 N	3364.055		0
3358.276		0000	3364.148		00
3358.416	Ti	3	3364.232		0000
3358.542		00	3364.362		00
3358.649	Ti-Cr	4	3364.408	Co	1
3358.771		00	3364.535		0 Nd?
3358.832		0	3364.749	Ni,-	3 d?
3358.929		00	3364.832		00
3359.035		2 N	3365.081		0000
3359.144		00	3365.167		0000
3359.248	Ni	3 N	3365.247		0000
3359.420	Co	1	3365.341		00
3359.542		1	3365.451		0000 N
3359.636	Fe?	2	3365.581		0
3359.769		1	3365.684		00
3359.823		2	3365.908	Ni	6
3359.936		1 N	3366.127		000
3360.066		0	3366.311	Ti, Ni	6 d?
3360.181		2	3366.494		000
3360.258		0	3366.594		000
3360.345		0	3366.687		0000
3360.444	Ni	2	3366.791		0000 N
3360.485	Cr	1	3366.931	Ni, Fe	3
3360.631		0	3367.009	Fe	3
3360.741		0	3367.117		000
3360.828		0	3367.233	Co	2
3360.988		0	3367.297	Fe?	1
3361.055	Ti	1	3367.434		00
3361.141		0	3367.527		0000
3361.241		1	3367.575		0
3361.327	Ti	8	3367.687		0
3361.421		2	3367.812		0
3361.568		0 N	3367.953		000
3361.704	Co,-	3 Nd?	3368.029	Ti, Ni, Fe	2
3361.906		1	3368.193	Cr,-	5 d?
3361.988		0	3368.319	Mn	1
3362.087	Ti	2	3368.382		000
3362.275		1	3368.496		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3368.580		0000	3374.271		000
3368.680		00	3374.358	Ni	4
3368.793		00	3374.487	Ti, Co	2
3368.860		00	3374.588	Fe	1
3368.956		0	3374.778	Ni	2
3369.083		3 d?	3374.872	Zr	1
3369.190		0	3374.981		000
3369.286		0	3375.068		0
3369.352	Ti, Mn	1	3375.231		00
3369.506		0 N	3375.351		0000
3369.633		0	3375.478		0 N
3369.713	Fe, Ni	6	3375.601		0000
3369.800		1	3375.698	Ni	1
3369.932		0	3375.768		000
3370.052		0	3375.866		0
3370.173		00	3375.991		0000
3370.330		0 N	3376.081		0000
3370.468	Co	2	3376.164		00
3370.584	Ti	2	3376 238		000
3370.770	Zr, Mn	1 Nd?	3376.341		0000
3370.933	Fe	4	3376.414		0
3371.020		000	3376.471	La	2
3371.110		0	3376.630	Fe	2
3371.246		00	3376.731		0000
3371.296		00	3376.814		0000
3371.431		0	3376.894		000
3371.535		00	3376.978		000
3371.593	Ti	3	3377.084		0000
3371.745		000	3377.202	Co	0 N
3371.852		00	3377.408		00
3371.899		00	3377.497		0000
3372.124	Ni,-	4	3377.622 } s	Ti	3
3372.225	Fe	1	3377.723 }	Ti	3
3372.314		0	3377.837		0000 N
3372.362	Ti	2	3377.943		0000 N
3372.488	Fe	0	3378.114		1
3372.609	Fe	00 N	3378.203		000
3372.759		0 N	3378.320		00
3372.901	Ti-Pd	{ 5	3378.476	Cr, Co?	2
3372.994		{ 5	3378.723		00
3373.105		0 N	3378.824	Fe	2
3373.229		000	3378.881	Co	1
3373.369	Co	0	3379.005	Mn	0 N
3373.452		0	3379.161	Fe	2
3373.555	Zr	0	3379.337	Ti, Cr	2 d?
3373.642		0	3379.514	Cr	2
3373.742		0000	3379 577		000
3373.872		0000	3379.687		0000
3374.016	Fe	1	3379.783		0000
3374.119		2	3379.843		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3379.961	Cr	3	3385.577	Fe	1
3380.060	Zr, Ti	1	3385.688	Fe	1
3380.157		0000	3385.809	Ti	1
3380.255	Fe	3	3385.861	Fe?	00
3380.397 [1]	Ti	3	3386.005		0000 N
3380.450 [1]		3	3386.085	Ti, Mn	3
3380.605		0	3386.310		00 N
3380.722	Ni	6 N	3386.408		000
3380.889	Sr?	1	3386.488		000
3381.026	Ni, La	5 Nd?	3386.588		000
3381.202		0000	3386.691		00 N
3381.269		1	3386.875		000
3381.490	Fe	2	3386.921		000
3381.632		000	3387.014		000
3381.669		000	3387.194		000 N
3381.786		0000	3387.307		000
3381.896		000	3387.444		0
3382.002		000	3387.554	Fe	2
3382.129	Mn	0	3387.600		0
3382.224		00 N	3387.762	Fe	1
3382.340		0	3387.854		00
3382.450	Ti	1	3387.988	Ti-Zr	5 d?
3382.549	Fe	2	3388.190		0000
3382.604	Di?	1	3388.311	Co	3
3382.724		000	3388.473	Zr	1
3382.825	Cr, Mn	4	3388.604		0 N
3382.926		0000	3388.761	La?	1
3383.036		00	3388.896	Ti	2
3383.129		0	3388.994		00
3383.232		0000 N	3389.107		1
3383.342		0000 N	3389.257		000
3383.449	Ag	000	3389.387		00
3383.512		0	3389.460		00
3383.629		000 N	3389.540		0
3383.709		0	3389.747		0000 N
3383.833	Fe	3	3389.884 s	Fe	2
3383.951	Ti	3	3389.960		0000
3384.133	Fe	3	3390.060		0000
3384.225		00	3390.154		000
3384.375		000	3390.244		000 Nd?
3384.461		000	3390.400		00
3384.561		000	3390.544		00
3384.728		0000 N	3390.654		000
3384.782		00	3390.736		000
3384.908		1	3390.819	Ti	0
3385.061		0000	3390.919		00
3385.167		0	3391.033		00 N
3385.215		000	3391.175	Ni	5
3385.361	Co	3	3391.243		1 N
3385.468		0000	3391.409		0000 N

[1] See note to 3335.299, etc.

Wave-length	Substance	Intensity and Character
3391.509		0000 N
3391.578	Cr	2
3391.726		0
3391.806		0000 N
3391.977		0
3392.109	Zr	2
3392.153	Fe	1
3392.259		0
3392.441	Fe	3
3392.633		00 N
3392.759	Fe	2
3392.813		1
3392.926	Ti	0
3393.029		0
3393.113	Ni	3
3393.160	Cr	1
3393.285	Zr	1
3393.427		0
3393.526	Fe	1
3393.845		1 Nd?
3393.980	Cr	2
3394.062	Fe	1
3394.220	Fe	1
3394.432	Cr	2
3394.518	Fe	0
3394.685	Ti	3
3394.746	Fe	3
3394.875		0000
3394.958		0000
3395.085		0000 N
3395.212		0
3395.408		00 N
3395.505	Co	3
3395.544		2
3395.750		0
3395.882		0
3396.012		000
3396.125		0
3396.178		0
3396.320	Ni	1
3396.437		0
3396.523		0
3396.642		000
3396.742		0000
3396.792		00
3396.965		0000
3397.062		0000
3397.116	Fe	3
3397.197		0000
3397.356		1

Wave-length	Substance	Intensity and Character
3397.451		0000
3397.571		00
3397.691	V?	1
3397.779	Fe	2
3397.931		00
3397.974		000
3398.151		0000 N
3398.244		0000 N
3398.357	Fe	1
3398.441		00
3398.511		0
3398.551		0000 N
3398.746	Ti	00 N
3398.839		000
3398.949		000
3399.059		0
3399.126		0000
3399.294		00
3399.376	Fe, Zr	2
3399.489	Fe	3
3399.654		0
3399.746		0000
3399.942		0 N
3400.153		0000 N
3400.279		000
3400.366		0000
3400.529		000
3400.629		0000
3400.779		1
3400.979		0000
3401.121		1
3401.307	Ni	1
3401.478		000
3401.664	Fe	3
3401.778		0000 N
3401.900		0
3401.992		000
3402.058		000
3402.208		000
3402.262		000
3402.352		000
3402.400	Fe	3
3402.553	Ti	3
3402.685		0
3402.842		0000
3402.925		000
3403.033		0
3403.145		0000 N
3403.288		0000 N
3403.404	Cr	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3403.478	Fe, Ti	2	3409.346	Fe	2
3403.572	Ni	2	3409.530		000 N
3403.725		000 N	3409.711	Ni	2
3403.826		0	3409.803		0
3403.925		0000	3409.950	Ti	2
3404.005		0000	3410.080		00
3404.128		0000	3410.170		1
3404.202		000 N	3410.313	Fe	2
3404.292		0000	3410.386	Zr	1
3404.413	Fe	2	3410.526		0000 N
3404.511	Fe	3	3410.696		00
3404.581		0000 N	3410.783		0000 N
3404.717	Pd	0	3410.923		00
3404.897		1	3411.035	Fe	2
3404.972	Zr	0	3411.160		00 Nd?
3405.044	C?	0	3411.274	Fe	1
3405.097		00	3411.360		0000
3405.217 } s	Co	2	3411.498	Fe	3
3405.302 }		2	3411.700		0000
3405.504		000	3411.883		000
3405.637		0000	3412.009		000
3405.716	Fe	0	3412.109		000
3405.837		0000 N	3412.162		0000
3405.971	Fe	1	3412.302		0000 N
3406.111		000 N	3412.481	Co	5
3406.254		00	3412.595		0000
3406.304		00	3412.775	Co	4
3406.391		0000	3412.909		0000 N
3406.491		0000	3413.019		000
3406.572 s	Fe	3	3413.275	Fe	5 d?
3406.697		0	3413.402		000 N
3406.943 s	Fe	5 d?	3413.542		00
3407.187		000	3413.597	Ni	2
3407.338	Ti	2	3413.651		2
3407.447		2	3413.782		0
3407.537		00	3413.855		00
3407.597	Fe	4	3413.935		0000
3407.693		3	3414.079	Ni	4
3407.844		0000 N	3414.269		00 N
3407.937	Di?	0	3414.399		000 N
3408.091		00 Nd?	3414.535		000 N
3408.217		0	3414.643		1
3408.317		0000 N	3414.769		1
3408.484		0000 N	3414.911	Ni	15
3408.637		000 Nd?	3415.050		1 Nd?
3408.811		000 N	3415.230		0
3408.911	Cr	3	3415.279		00
3409.070		1	3415.462		0000 N
3409.210		0000	3415.575		0000
3409.302	Co	2	3415.672	Fe	3

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3415.815		0	3422.033		0000
3415.922		00 N	3422.087		0000
3416.029		0000	3422.260		1
3416.164		3	3422.347		0000
3416.274		0000	3422.468	Ni	1
3416.421		1	3422.629	Fe	4
3416.541		0000	3422.794	Fe	3
3416.644		000 N	3422.892	Cr	4
3416.771		00	3423.016	Ni	1
3416.808		0	3423.153		0000 N
3416.914		00	3423.307		000 N
3417.001		00	3423.380		00 N
3417.095	Ti	1	3423.451		000 N
3417.198		00	3423.667		00 N
3417.301	Co	3	3423.760		0 N
3417.401	Fe	1	3423.848	Ni	7
3417.491		000	3423.972		0 N
3417.618		0000	3424.127		0
3417.681		0000	3424.311		00
3417.819	Co	00	3424.432	Fe	4
3417.948	Fe	2	3424.579		0000 N
3418.002		2	3424.646	Co	0
3418.161		0000	3424.732		000
3418.303	Fe	1	3424.846		000
3418.448		0000 N	3424.966	Zr	00
3418.654	Fe	5	3425.152	Fe	4
3418.864		000 N	3425.196		000
3419.013		1	3425.432		0000 N
3419.108		0000 N	3425.579		0000 N
3419.282	Fe	1	3425.716 s		2
3419.424		000 N	3425.879		0000 N
3419.554		000 N	3425.976		00
3419.836	Fe	2	3426.102		000
3420.013		000	3426.226		000
3420.133		000	3426.349		0000
3420.240		00	3426.466	Fe	3
3420.360		000	3426.535	Fe	3
3420.417		00	3426.769	Fe	3
3420.575		0	3426.807		2
3420.620		00	3426.929		0000
3420.730		000	3427.046		0000
3420.880	Ni?	2	3427.126	Fe?	2
3420.940	Mn	00	3427.263 s	Fe	3
3421.147		000	3427.340		1
3421.253		0000 N	3427.492		0000
3421.353	Ni, Cr, Pd	4	3427.596		0000
3421.482	Ni	2	3427.656		00
3421.620		0000 N	3427.746		0000 N
3421.758	Co	0	3427.899		000 N
3421.860		0	3427.972		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3428.082		0000 N	3434.117		0000
3428.154		0	3434.183		0
3428.341	Fe, Co	4	3434.259		0
3428.459		0000	3434.383		0000
3428.561		1	3434.512		000
3428.626		1	3434.626		0000
3428.776		000	3434.746		0000
3428.892	Co	2	3434.829		0000
3429.066		000	3434.962		000
3429.172		0000	3435.032		000
3429.282		0000 N	3435.102		00
3429.468		00	3435.179		0000 N
3429.605		0000	3435.296		000 N
3429.718		0000 N	3435.382		000 N
3429.851		00	3435.509		0000 N
3429.951		000	3435.628		1
3430.071		0000 Nd?	3435.729		00
3430.218		0000 N	3435.819	Cr	0
3430.295		000	3435.962	Cr	0 N
3430.428		00	3436.174		1
3430.545		00 N	3436.250		0
3430.671	Zr-	1	3436.332	Cr	2
3430.777		0000 N	3436.472		0000 N
3430.870		0000 N	3436.552		000 N
3431.020		000	3436.666		0000 N
3431.090		000	3436.786		0000
3431.207		0000	3436.882		000
3431.320		0000	3436.976		0000 N
3431.423		00	3437.116		000 N
3431.590		0000 N	3437.190	Fe	3
3431.721	Co	4	3437.282	Zr	00
3431.830		000	3437.427	Ni	5 d?
3431.965	Fe	3	3437.616		0000Nd?
3432.077		000	3437.772		00
3432.157		0	3437.829		00
3432.270		000	3437.926		0000
3432.350		0000	3438.012		0000
3432.447	Co	0	3438.094	Fe	2
3432.550		00	3438.236		000
3432.707		0000	3438.376	Zr	2
3432.863		0	3438.455	Fe	1
3433.023		000	3438.556		0000 N
3433.163	Co	3	3438.639		000 N
3433.212	Cr, C?	2	3438.851		000 N
3433.290	Pd	0000	3439.092	Mn?	2
3433.453	Cr	3	3439.171	Fe	2
3433.591		0	3439.268		0000 N
3433.715	Ni, Cr	8 d?	3439.365		000 N
3433.905		0 N	3439.478		00 Nd?
3434.053		0000	3439.635		000 N

ON THE APPLICATION OF INTERFERENCE METHODS TO THE DETERMINATION OF THE EFFECTIVE WAVE-LENGTH OF STARLIGHT.

By George C. Comstock.

The experiments to be set forth in the present paper grew out of and are collateral to an investigation of the atmospheric refraction contained in *Publications of the Washburn Observatory*, Vol. IX. The discussion of those observations, pp. 185–190, seemed to show a sensible difference in the amount of the refraction, depending upon the color of the star in question, a difference which might indeed be expected *a priori* since, the color being produced by selective absorption in the stellar atmosphere, it may be assumed that the average wave-length and the corresponding refraction of the light received from a red star will be in some measure different from that of a star in whose spectrum the violet and blue rays have not suffered an absorption relatively so great.

But since the colors thus produced cannot, in general, be saturated and will usually be quite different from the pure spectral colors, the average wave-length of the light of a given star must not be assumed to be even approximately determined by matching its color, as nearly as may be, with that of a definite part of the solar spectrum, and the same holds true, *a fortiori* for the effective wave-length if we understand by that term the wave-length of that part of the stellar spectrum which the observer adopts as determining the position of the star and upon which his attention is concentrated in the observing. It does indeed result, at least apparently, from the investigation above cited that the wave-lengths determined for the stellar colors there encountered are approximately those of corresponding colors in the solar spectrum and, erroneously as I now think, I have regarded this agreement as a confirmation of the reality of the color effect there investigated.

Recognizing that no very considerable weight can attach to a determination of the color effect made as was the above, I have endeavored to supplement and control it by an entirely independent method, which should give immediately a determination of the effective wave-length of the light of a given star. The term effective wave-length as above defined is nearly equivalent to the wave-length of the (visually) brightest part of the star's spectrum, it being assumed that in ordinary visual observations the observer's attention is concentrated upon this part of the spectrum into which the atmosphere transforms the stellar image.

This assumption is perhaps open to question in the case of very bright stars, but these may be reduced to the case above considered by the use of screens or other appropriate device for diminishing their brightness, recourse to which is frequently had upon quite other grounds.

The value of such determinations of effective wave-length for the more refined investigations of the astronomy of position is apparent and is frequently noted in connection with the determination of the solar parallax from observations of the planets, but little attention has hitherto been paid to a quantitative determination of the color effect. In the literature of the subject accessible to me I have been able to find only one attempt at a determination of effective wave-lengths which can be designated as in any degree successful (Schwarzschild, *A. N.*, No. 3335), and that is limited to a consideration of the mean result furnished by a large number of stars taken without regard to individual differences. The investigations of von Konkoly (*Observatory*, 4, 11) upon the relation of color to wave-length are directed to a different end and his numerical results, which are based upon a comparison of the saturated colors of a Geissler tube with the dilute colors of five stars, give no clue to their effective wave-lengths, as the term is here employed.

As a means of dealing with the problem of differences in effective wave-length I have had recourse to methods based upon the interference of light produced by placing between the star

and the observing telescope (the 40^{cm} Clark equatorial of the Washburn Observatory) an opaque screen in which are cut two narrow rectangular apertures of equal dimensions and with their homologous sides parallel. When light from a bright star is transmitted through these apertures there is produced in the focal plane of the objective a central image of the star and upon opposite sides of this a series of fringes of rapidly diminishing brightness which soon merge into each other and, in the case of very bright stars, become a faint and narrow brush of light streaming away from the central image parallel to the line joining the centers of the apertures. For stars of moderate brightness, third to sixth magnitude, a certain number of the fringes are indistinguishable in appearance from faint stars and the central portion of the interference pattern resembles a multiple star of symmetrical arrangement, the relative position of whose several parts may be determined with a micrometer with all the precision of similar double star observations. The theory of these fringes is contained in the text books of optics, and reference may also be made to a peculiarly succinct and elegant treatment of the subject by M. Hamy (*Bull. Astron.*, 10, 489)

In general the intensity of the light at any point of the interference pattern is represented by a definite integral whose limits are so determined as to include the entire angular extent of the source of light, but in the case of a fixed star this area may be replaced by a single element of the integral, from which all of the light is supposed to proceed, and if we put (see the article of M. Hamy above cited)

a = the linear width of each slit in the screen.

na = the distance between the axes of the slits.

λ = the wave-length of the light in question.

C = a constant.

θ = the angular distance from the central image of any point on the axis of the interference pattern

we shall have for the intensity of the illumination at any point on the axis of the pattern by a little transformation of M. Hamy's equations

$$I = \left[C \frac{\sin \alpha}{\alpha} \cos n\alpha \right]^2,$$

where α is an auxiliary quantity defined by the relation

$$\alpha = \pi \frac{a}{\lambda} \theta .$$

In the case of an ordinary star whose light is not monochromatic the total brightness must be found by multiplying this value of I by $d\alpha$ and integrating between limits corresponding to the extreme values of λ in the visible spectrum. This process is, however, quite unnecessary for those parts of the pattern in which the fringes are indistinguishable in appearance from faint stars, *e. g.*, of the tenth magnitude, since the total amount of light here present is so small that only the brightest part of the spectrum is visible, and the limits of integration are brought so close together that the single element of the integral, I, may be taken as proportional to the brightness and as determining, through α and θ, the value of λ corresponding to the point of maximum brightness in the spectrum, *i. e.*, the effective wave-length, as shown below.

It is evident that I is a periodic function of α and the points of maximum illumination may be found by differentiating the function with respect to α. We thus obtain as the criterion for the positions of the fringes the transcendental equation

$$\alpha [1 - n \tan \alpha \tan n\alpha] = \tan \alpha ,$$

which may be solved by trial when n is given. For the apparatus which I have employed

$$n = 2, \qquad a = 27^{mm}.0, \qquad h = 373^{mm}.5,$$

where h represents the length of the slits. The first few values of α corresponding to $n = 2$ are

α_0	α_1	α_3	α_5	α_7
$\pm 0^\circ.0$	$\pm 82^\circ.2$	$\pm 265^\circ.9$	$\pm 447^\circ.5$	$\pm 628^\circ.3$

It will be noted that, with exception of the first number, these values are approximately the odd multiples of $\frac{\pi}{2}$ and the distinguishing subscripts are assigned with reference to this relation.

Since α is a function of the wave-length of light, it appears

that the maximum illumination must occur at different points for different values of λ, and the fringes therefore be iris bordered, but this appearance is perceptible to the eye only in the case of the central fringes of a very bright star, since the divisor a^2 which appears in the expression for I corresponds to so rapid a diminution of the brilliancy of successive fringes that only those rays which most strongly excite the retina are visible, the outer fringes being reduced to minute stellar points whose distance from the central image, θ, or from each other, 2θ, may be measured with the micrometer and employed for a determination of the corresponding effective wave-length from the equation

$$\lambda = \pi a \left(\frac{\theta}{a}\right)_i,$$

where i denotes the order of the fringe.

In the determination of wave-lengths, I have uniformly measured the distance, 2θ, between corresponding fringes on opposite sides of the central image, using the most remote fringes which could be seen with sufficient precision to permit of accurate settings of the micrometer threads.

I have observed the common precautions which the experience of double star observers has indicated as essential to the accurate measurement of distances, and in order to bring into the most favorable position the objects whose distance was to be measured, the screen was always placed in front of the objective with the axis of the slits parallel to the declination axis of the telescope.

In order that the observations should extend over a considerable range of stellar colors, a part of the stars to be observed were selected from Krüger's *Catalog der farbigen Sterne*, and the color numbers, rounded off to the nearest unit, there assigned to the several stars are given below. In some cases it has been necessary to translate a literal symbol into a numerical one. Another portion of the observing programme has been selected from the *Draper Catalogue*, viz., bright stars whose spectrum is there designated by the letter *A*. The color number 0 is assumed to correspond to these stars. Two faint companions

to brighter stars which appear to me distinctly green or bluish green are indicated by the symbol *G*, since Krüger's numerical symbols do not extend to these colors.

Since the present series of observations is purely experimental, I have not sought to multiply observations of the same star, but have for the most part confined myself to two independent determinations of wave-length for each star of the list. For a few stars, however, a larger number of determinations has been made, and I give below the separate results in every case where more than four observations of a single star are available. All observations made on the first fringe are rejected, since the small value of α for that fringe gives very large effect to the accidental errors of observation. The wave-lengths are expressed in millionths of a millimeter, and the number of the fringe from which each determination was made is given.

Vega	Altair	μ Cephei
572_3	558_3	576_3
560_5	546_3	565_3
559_5	557_5	570_3
554_5	561_5	575_5
564_5	558_7	583_5
549_7	555_7	
570_7		

Vega and Altair are typical white stars, while μ Cephei, the garnet star of W. Herschel, is called the reddest lucid star in the northern hemisphere. The great brilliancy of Vega gives to its fringes a sensible width, which in some measure diminishes the accuracy of the observing.

The differences in the individual determinations above shown are not wholly accidental, and a comparison of all of the data shows the following systematic differences between results derived from different fringes:

Fringes	$\Delta\lambda$	p. e.
$7-5$	$+1^{\mu\mu}.0$	± 0.8
$5-3$	$+5\ .5$	± 1.1
$3-1$	$-6\ .5$	....

These differences are sufficiently explained by the supposition that the measured distance 2θ between the fringes designated by the subscript 3 requires a systematic correction of $+0''.13$. This correction agrees in sign and very approximately in magnitude with systematic corrections to my micrometer measurements derived in connection with observations of double stars, and regarding it as well established, I assume the corresponding correction of $+6^{\mu\mu}.0$ to all wave-lengths derived from fringe 3, and treat the results from the other fringes as free from systematic error.

After the application of this correction, I find from 124 residuals furnished by 51 stars a probable error $r_1 = \pm 3^{\mu\mu}.4$ for a single determination of λ. The measure of precision thus indicated, while very small by comparison with standard determinations of the wave-length of the Fraunhofer lines, is sufficient to furnish some conclusions respecting the influence of color upon effective wave-length, and the data from which these conclusions are to be drawn is set forth in the following table, whose first four columns seem to require no explanation further than the statement that the letters, *A*, *B*, placed after the name of a star denote, respectively, the brighter and fainter components of a double star. In the last three columns λ_0 denotes the mean value of the effective wave-length, *n*, the number of observations included in this mean, and *D. C.* the type of spectrum assigned the star in the *Draper Catalogue*. The character ? appended to these symbols is taken from the *D. C.*, and denotes that the results obtained from different plates were discordant after a second examination. The same symbol in the fourth column is assigned by myself and indicates an uncertain identification of the color.

Star	R. A.	Dec.	Color	λ.	n	D. C.
α Lyrae	18h 33m	38°.7	0	562	7	A
α Aquilae	19 45	8.6	0	559	6	A
α Urs. Min.	1 19	88.7	0	562	2	A
α Androm.	0 3	28.5	0	559	2	A
ο Androm.	22 57	41.8	0	565	2	A
σ Androm.	0 13	36.2	0	568	2	A
α Pegasi	23 0	14.7	0	560	2	A
γ Pegasi	0 8	14.6	0	568	1	A
η Cassiop.	0 43	57.2	0?	570	2	F
ψ Cygni	19 54	52.0	0?	559	1	A
θ Cygni	19 32	49.9	0?	563	1	F?
β Lyrae	18 46	33.2	1	563	4	G
γ Delphini, A	20 42	15.8	1	573	4	K?
γ Delphini, B	20 42	15.8	1?	573	1	...
ι Aquilae	19 32	−1.5	1	569	2	A
35 Arietis	2 38	27.3	1	565	2	A
υ Androm.	1 31	40.9	1	564	2	F
α Aquarii	22 1	−0.8	1?	576	2	K?
Androm.	0 12	38.1	2	562	2	A
δ Draco	19 12	67.5	2	564	2	L?
ξ Pegasi	22 42	11.7	2	576	4	F
ψ' Aquarii	23 11	−9.6	2	575	2	H
Capricorni	21 17	−17.3	3	574	2	H?
5 Lacertae	22 10	39.2	3	578	2	I
β Urs. Min.	14 51	74.6	4	574	2	L?
λ Pegasi	22 42	23.0	4	580	2	K(?)
35 Pegasi	22 23	4.2	4	580	2	K
ε Pegasi	21 39	9.4	4	564	2	K
ι Cephei	22 46	65.7	4	580	2	I?
λ Androm.	23 33	45.9	4	576	2	K
ζ Aurigae	4 56	40.9	4	564	2	I?
ζ Cephei	22 7	57.7	5	574	2	K?
1 Lacertae	22 12	37.2	5	578	3	I?
3 Lacertae	22 20	51.7	5	577	2	I
11 Lacertae	22 36	43.8	5	574	2	H
β Androm.	1 4	35.1	5	570	2	K?
γ Androm., A	1 58	41.8	5	568	2	K
γ Androm., B	1 58	41.8	G	564	1	...
γ Aquilae	19 42	10.4	6	573	2	K
τ Aquarii	22 44	−14.1	6	581	2	M?
λ Aquarii	22 47	−8.1	6	579	4	M?
3 Aquarii	20 42	−5.4	6	570	2	...
α² Capricorni	20 12	−12.8	6	572	2	H?
30 Piscium	23 57	−6.6	6	580	2	H
δ Sagittae	19 43	18.3	6	573	2	M?
γ Sagittae	19 54	19.2	7	575	2	K
β Pegasi	22 59	27.5	7	572	2	M?
ψ Pegasi	23 53	24.6	7	580	2	H
β Cygni, A	19 26	27.7	7	571	3	Q?
β Cygni, B	19 26	27.7	G	574	2	A?
5 Lacertae	22 25	47.2	7	577	2	H?
α Orionis	5 49	7.4	7	570	2	M?
R Lyrae	18 52	43.8	7	570	3	M?
α Tauri	4 30	16.3	7	570	4	K?
μ Cephei	21 40	58.3	8	577	5	M?

Even a casual inspection of these values of λ_0 will suffice to show a progressive increase in the numbers, but this sequence is best brought out by taking mean values for groups of stars selected with reference either to the color number or to the type of spectrum. Thus, with respect to color we have

Color No.	Stars	λ_0
0	11	$563^{\mu\mu}.2$
1–2	11	569 .1
3–4	9	574 .4
5–6	14	573 .8
7–8	9	573 .6

With respect to the type of spectrum, the symbols of the *Draper Catalogue* being translated in accordance with the introduction to that volume, we have

Class	Stars	λ_0
I	13	564.0
II	31	572.6
III	7	574.6

These tables agree in differentiating the white stars of the Sirian type from the yellow or solar stars by a much wider interval than separates the latter from the red stars with banded spectra. Indeed, the difference in the values of λ_0 coresponding to the last two classes but little exceeds the probable error of the tabular numbers. In view of the limited number of stars observed it will be best to restrict conclusions from the preceding data to the statement that the effective wave-length of the light of stars which are distinctly colored is approximately $9^{\mu\mu}$ greater than that of white stars; and that stars of the deepest red color do not sensibly differ in effective wave-length from those of a yellow hue.

If we adopt Kayser and Runge's value for the atmospheric dispersion of light (*Astronomy and Astrophysics*, No. 115) it may readily be shown that at a zenith distance of 45° the difference of $9^{\mu\mu}$ in effective wave-length corresponds to a difference of about $0''.03$ in the refraction, and this may obviously be neglected in all cases save those in which the utmost possible precision is required.

The observations above set forth are to be considered as a first attempt, with homemade apparatus, at applying interference methods to the problem in hand. The screen was cut from a piece of pasteboard, and the adopted average width of the slits, $a = 27^{mm}.0$, is uncertain to the extent of $0^{mm}.1$ or $0^{mm}.2$ corresponding to something less than 1 per cent. in the absolute values of the wave-lengths. The relative values are, however, free from this source of error, since the same screen was used in all of the observations.

A serious limitation upon the more extended use of the method is the difficulty attending its application to faint stars. With the apparatus which I have employed the sixth or possibly the seventh magnitude constitutes the limit at which the third fringe is bright enough to be satisfactorily measured, and if the observations are to be extended below this limit the first fringe must be used and a large part of the precision of the results sacrificed.

WASHBURN OBSERVATORY,
November 24, 1896.

REMARKS ON THE ARTICLES OF MR. E. J. WILCZYNSKI IN THIS JOURNAL VOL. IV. NO. 2.

By PAUL HARZER.

IN the first of these articles my mathematical treatment of the solar rotation in *A. N.* 3026 is accused of lacking vigor. On the contrary I shall show that the deductions of Mr. Wilczynski are quite erroneous.

The principal error is the conclusion drawn from equations (6), that ω^2 does not depend upon c and depends only upon $\sqrt{a^2+b^2}$. This conclusion is tenable only in the case of the symbol

$$dP = \frac{dp}{\rho}$$

being really integrable. But in general from equations (6) or, more clearly written, from

$$\frac{dV}{da} - \frac{1}{\rho}\frac{dp}{da} = -\omega^2 a \quad \frac{dV}{db} - \frac{1}{\rho}\frac{dp}{db} = -\omega^2 b \quad \frac{dV}{dc} - \frac{1}{\rho}\frac{dp}{dc} = 0$$

we deduce the relations

$$\frac{d^2V}{da\,db} - \frac{1}{\rho}\frac{d^2p}{da\,db} = -a\frac{d\omega^2}{db} - \frac{1}{\rho^2}\frac{d\rho}{db}\frac{dp}{da} = -b\frac{d\omega^2}{da} - \frac{1}{\rho^2}\frac{d\rho}{da}\frac{dp}{db}$$

$$\frac{d^2V}{da\,dc} - \frac{1}{\rho}\frac{d^2p}{da\,dc} = -a\frac{d\omega^2}{dc} - \frac{1}{\rho^2}\frac{d\rho}{dc}\frac{dp}{da} = -\frac{1}{\rho^2}\frac{d\rho}{da}\frac{dp}{dc}$$

$$\frac{d^2V}{db\,dc} - \frac{1}{\rho}\frac{d^2p}{db\,dc} = -b\frac{d\omega^2}{dc} - \frac{1}{\rho^2}\frac{d\rho}{dc}\frac{dp}{db} = -\frac{1}{\rho^2}\frac{d\rho}{db}\frac{dp}{dc}$$

and hence

$$a\frac{d\omega^2}{db} - b\frac{d\omega^2}{da} = \frac{1}{\rho^2}\left(\frac{d\rho}{da}\frac{dp}{db} - \frac{d\rho}{db}\frac{dp}{da}\right)$$

$$\frac{d\omega^2}{dc} = \frac{1}{a\rho^2}\left(\frac{d\rho}{da}\frac{dp}{dc} - \frac{d\rho}{dc}\frac{dp}{da}\right) = \frac{1}{b\rho^2}\left(\frac{d\rho}{db}\frac{dp}{dc} - \frac{d\rho}{dc}\frac{dp}{db}\right)$$

Therefore in general neither $a\dfrac{d\omega^2}{db} - b\dfrac{d\omega^2}{da}$ nor $\dfrac{d\omega^2}{dc}$ are vanishing.

Another error involves the formulæ (5) as they contradict the supposition that a, b, c represent the values of x, y, z, for $t = 0$. The correct formulæ are:

$$x = a \cos \omega t - b \sin \omega t \qquad y = a \sin \omega t + b \cos \omega t \qquad z = c$$

The equations (6) remain unaltered by introducing these formulæ into equations (1).

By means of the erroneous formulæ (5) Mr. Wilczynski concludes that all conditions are satisfied, it being easy to prove that D vanishes. He is here overlooking the fact that a vanishing value of D is physically impossible, D representing the relation of the elementary volumes for the times $t = t$ and $t = 0$. The correct formulæ for x, y, z, giving

$$D = \Delta + \left(a\frac{d\omega}{db} - b\frac{d\omega}{da}\right)t,$$

the condition of continuity requires the expression

$$\rho\left(\Delta + \left(a\frac{d\omega}{db} - b\frac{d\omega}{da}\right)t\right) = \rho\left(\Delta + \frac{1}{2\rho^2\omega}\left(\frac{d\rho}{da}\frac{dp}{db} - \frac{d\rho}{db}\frac{dp}{da}\right)t\right)$$

to be invariable for a moving elementary mass.

This condition is fulfilled only in consequence of certain suppositions regarding the constitution of the revolving mass, for instance the supposition that the density and the pressure are the same at all similarly situated points of all plane sections across the axis of rotation. Then ρ does not change for a moving elementary mass and ρ, p and ω^2 depend only upon $\sqrt{a^2 + b^2}$ and $\sqrt{a^2 + b^2 + c^2}$; but even in this special case the value of $\frac{d\omega^2}{dc}$ does not vanish.

I think that the vanishing value of $\frac{d\omega^2}{dc}$ must have led Mr. Wilczynski to the objection against my treatment of the problem. But the error is his, not mine.

In view of these facts Mr. Wilczynski's considerations cannot be maintained; for if they are legitimate they ought to be limited to cases of integrable values of $\frac{dp}{\rho}$, for instance to incompressible fluids or to gases at *constant* temperature, *i. e.*, to cases the existence of which we have no reason to assume anywhere in nature.

GOTHA, October 10, 1896.

RESEARCHES ON THE ARC-SPECTRA OF THE METALS. III. COBALT AND NICKEL. III.[1]

By B. Hasselberg.

SPECTRUM OF NICKEL.

Nickel λ	R.	i Ni	i ⊙	Remarks	Liveing and Dewar
3458.59		4	4	Very diffuse. Reversed.	58.45
61.78		4	4	Very diffuse. Reversed.	61.66
62.95		1	2	Ni ?	
67.63		2.3	2	Sharp.	67.35
69.64		2.3	3	Sharp.	69.45
72.68		3.4	3	Diffuse. Reversed.	72.45
78.48		1	1.2		
79.43		1	1		
80.36		1	1		
[illegible].04		2.3	2		85.75
——	3486.04				
93.10		4.5	4	Very diffuse. Reversed.	92.85
96.50		1	1		
3501.00		3	2.3		00.55
02.76		2	2		
07.85		2	2	Sharp.	07.86
10.47		4	4	Diffuse. Reversed.	10.26
——	3510.99				
14.06		2.3	2.3		
15.17		4.5	4	Very diffuse. Reversed.	14.96
16.35		2	1.2		
18.80		2	2		18.56
19.90		3	2.3		19.66
23.19		1.2	1.2		
24.65		5	4	Very diffuse. Reversed.	24 46
28.13		2.3	2		
29.03		1.2	1		
29.76		1	1		
30.73		1.2	1.2		30.47
33.89		1	1	Diffuse.	
——	3540.27				
48.34		2.3	2.3	Also Mn.	48.07
51.66		2.3	2		51.37
53.63		2	2		53.37
——	3558.67				
60.08		1	1		
61.91		2	1.2	Very sharp.	61.67
66.50		4.5	4	Very diffuse. Reversed.	66.27

[1] Continued from p. 366.

Nickel λ	R.	i Ni	i ⊙	Remarks	Liveing and Dewar
3571.99		3.4	3	Diffuse. Reversed.	71.78
77.37		1	1		
——	3583.48				
88.08		2.3	2.3	Very sharp.	
97.84		3.4	3.4	Diffuse.	97.58
3602.41		2.3	2		
——	3605.63				
07.02		1	1		
09.44		2.3	2		
10.60		4	3	Reversed.	10.38
11.58		1	1		
12.86		3.4	2.3		12.68
19.52		5	5	Very diffuse. Reversed.	19.38
24.87		3	2.3	Very sharp. ⊙ line double { 24.87 Ni. .97 Fe, Ti. }	24.68
30.04		1.2	1.2		
35.10		2	2	Very sharp. ⊙ line a close double.	35.49
——	3635.62				
41.78		1.2	1.2		
42.58		1	—	} Ni ?	
44.13		1	—		
——	3658.69				
62.10		2	1.2	Very sharp.	
64.24		3	2.3	Very sharp. ⊙ double { 64.16 Fe. .24 Ni.	63.99
68.35		1	1.2		
69.38		2	2	Very sharp. ⊙ double { 69.30 Fe. .37 Ni.	
70.57		2.3	2.3	Very sharp.	70.29
74.28		3.4	2	Very sharp. ⊙ double { 74.18 Fe. .28 Ni.	73.99
83.65		1	?		
——	3684.26				
88.58		2.3	2.3	Very sharp.	88.19
94.10		2	2.3	⊙ line a close double { 94.10 Ni. .20 Fe.	
97.04		1	1		
3713.49		1	1		
13.87		1	1		
15.61		1.2	2	•	
——	3716.58				
22.63		3	4	Ni line on the red edge of the ⊙ line 22.70 Fe, Ti.	
24.95		1.2	1.2		24.80
29.05		1	2		
30.88		1.2	2		
36.94		3.4	3.4	Very sharp.	36.70
39.36		2.3	2	⊙ line triple { 39.26 Fe. 36 Ni. .46 Fe.	
39.89		1	1.2		
——	3743.50				

Nickel λ	R.	i Ni	⊙	REMARKS	Liveing and Dewar
3744.68		2.3	2	Very sharp.	
49.15		2	2.3	Very sharp. ⊙ line probably double.	
62.76		2	1		
69.58		1	1.2		69.50
72.70		2.3	2	Sharp.	
—	3774.48				
75.71		4.5	2.3		75.62
78.22		1.2	1.2		
83.67		4	2.3		83.62
92.48		2.3	2	Very sharp.	
93.75		3	2	Very sharp.	
—	3805.49				
3807.30		4	3		07.22
11.46		1	1.2	⊙ line a close double { 11.46 Ni. .56 Ti.	
29.49		2.3	—		
31.82		3	3		
32.44		2.3	4		32.32
33.02		2	1.2		
—	3836.23				
44.40		1.2	2	Very diffuse.	
44.71		1.2	1		
58.40		4.5	3	Reversed.	58.42
63.21		2.3	1.2		
—	3864 44				
71.73		1.2	1		
—	3886.43				
89.80		2.3	2	Very sharp.	
3905.67		1.2	4	Probably a foreign line.	
09.10		1.2	1.2	Very diffuse.	
12.44		1.2	1.2	Very diffuse.	
13.12		2	1.2		
14.65		1	?		
—	3916.87				
44.25		3.4	—	Very diffuse.	
—	3954.00				
54.61		1.2	—	Very diffuse.	
70.65		2	—	Very diffuse.	
72.31		2.3	2		
73.70		4	2.3	⊙ line a close double { 73.70 Ni. .81 Fe.	
74.83		2	—	Very diffuse.	
—	3977.89				
84.18		2	—	Very diffuse.	
94.13		2	—	Very diffuse.	
95.45		3.4	2.3		
—	4003.92				
4006.30		2	1.2		
10.14		1.2	?		
17.65		2	—	Very diffuse.	
19.20		1.2	1.2		
22.20		1	—		

Nickel λ	R.	i Ni	⊙	REMARKS	Thalén
4025.26		1.2	1.2		
——	4034.64				
46.91		1	—		
57.45		1	—		
——	4062.60				
64.55		2	—		
69.39		1	—		
73.08		1	—		
75.05		1.2	—	Sharp.	
75.75		1.2	—	Diffuse.	
86.30		1	1		
——	4088.72				
4104.37		1	—		
16.14		2	1		
21.48		3	3	Sharp. 21.41 Cr.	
——	4121.97				
23.96		1	—		
38.67		1	?		
42.34		1	1.2		
42.47		2	1.2		
43.12		1	1		
50.55		1.2	1.2	⊙ has 50.48 Fe.	
——	4157.95				
64.82		1	1	Sharp.	
67.16		1.2	—	Diffuse.	
84.65		1.2	—		
——	4185.06				
95.71		2.3	1.2	⊙ a close double $\left\{\begin{array}{l}\text{95.71 Ni.}\\\text{.77 Fe.}\end{array}\right.$	
4200.61		2	1.2	Sharp.	
01.88		2.3	1.2	Sharp.	
02.33		1	—		
21.87		1	—		
——	4231.15				
31.23		2	—		
36.55		1.2	—		
52.25		1	1		
——	4254.50				
84.83		2.3	1.2		
88.16		3.4	2	⊙ double $\left\{\begin{array}{l}\text{88.05}\\\text{.15}\end{array}\right.$	
——	4293.25				
96.06		3	1		
97.15		1	2		
98.68		1.2	1		
98.94		1	1.2		
4307.40		1.2	1.2		
——	4308.03				
25.49		1.2	1.2	Diffuse.	
25.75		2.3	1.2	Sharp.	
30.85		2.3	1.2	Intensity of the Ni line variable.	
31.78		3	—		

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
——	4343.39				
4356.07		2	1.2	Diffuse.	
59.73		3	2	Sharp. ⊙ line the middle line of a Close triplet. Cr has 59.78, Ba 59.80.	
68.45		2	1		
70.21		1.2	1	Diffuse. ⊙ perhaps double.	
——	4376.10				
83.05		1	—		
84.68		2.3	1.2		
86.62		1.2	?	Diffuse.	
90.00		2	1		
90.47		1.2	?	Diffuse.	
98.78		1	1		
99.75		2	1		
4401.02		2	1.2		
01.70		4.5	2	⊙ line double { 01.60 / .70 Ni	
——	4407.85				
10.70		2.3	2	Diffuse.	
23.24		1.2	1		
——	4435.13				
37.17		2.3	2		
37.75		2	—		
41.64		1	—		
42.61		2	—		
50.29		1	—		
50.44		1	—		
——	4456.05				
59.21		4.5	2	⊙ line double { 59.20 Ni / .30 Fe }, (K.—R:59.30)	
62.59		4	2		
63.57		2	1.2		
66.54		2	1		
70.61		4	2.3		
81.30		1	1.2	Diffuse.	
90.71		2	1	Diffuse.	
——	4494.17				
4506.53		1	—		
——	4508.46				
13.20		2	1		
20.20		2.3	1	Very sharp.	
——	4531.40				
47.14		2	2	⊙ has { 47.15 Ni / .25 Fe } (K.—R:47.20)	
47.44		2.3	1.2		
51.45		2	1		
53.37		1.2	1		
——	4554.21				
60.10		2	1		
67.59		1	—		
80.77		1.2	1.2		
——	4588.38				

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
4592.69		3.4	2.3	⊙ has { 92.70 Ni / .80 Fe } (K.—R:92.81)	
95.07		2	1.2		
96.11		2	—	Diffuse.	
4600.51		3	2		
05.15		4	2.3		
06.37		2.3	1.2		
14.85		1	1		
18.22		1.2	1	⊙ line double { 18.15 / .22 Ni	
——	4611.45				
47.47		1.2	1		
48.82		3	2.3		
55.85		1+	1		47.88
67.16		1.2	1.2		
67.96		2	1.2		
——	4668.30				
75.80		1	1		
86.39		2.3	2	Sharp. Cr. has 86.38; lines probably divided	
——	4686.39				
4701.52		1	1.2		
01.72		2	1.2		
——	4703.18				
03.96		2.3	2	Diffuse.	
12.24		1	1		
14.59		4.5	3		14.54
15 93		3	2		
——	4727.63				
28.06		1	1		
29.50		1	1		
32.00		2	1.2		
32.66		2	1.2		
52.30		1.2	1.2	Coincides with a Cr line. The other strong lines of Cr in this neighborhood are missing.	
52.58		2	1.2		
——	4754.23				
54.95		1.2	1.2		
56.70		3	2		55.84
62.78		1.2	1.2		
64.07		2	2		
73.55		1	1		
——	(4780.10)			([1])	
86.42		1	1.2		
86.66		3	2.3		86.64
92.98		1	1.2		
——	4805.25				
4807.17		2	2		
09.05		1	1		
12.15		1	1		
14.77		1	1		
17.97		1	1.2		
21.29		1	1.2		

[1] The lines λ 4780.10, 4950.25, and 5227.40 are taken from Rowland's map of the solar spectrum.

Nickel λ	R.	i Co	⊙	Remarks	Thalén
——	4824.33				
4829.18		3	2.3		29.30
31.30		2.3	2.3		31.10
22.86		1.2	2		
38.80		2	2		
43.27		1	1.2		
52.70		1.2	2	Diffuse.	
55.57		3	2.3		55.60
57.57		1.2	2		
——	4859.93				
64.11		1.2	1	Diffuse.	
64.46		1	1.2	Diffuse.	
66.42		3.4	2		66.20
70.97		2	2	Cr has a strong line at 70.96; divided from Ni, and λ Cr < λ Ni	
73.60		2	2		73.80
74.95		1	1		
87.16		1.2	2		
——	4890.94				
4904.56		3.4	2.3		04.70
12.22		1.2	1.2	Diffuse.	
14.15		2	1.2	Diffuse.	
18.53		2.3	2	Sharp.	18.40
18.86		1	1.2		
25.74		1.2	1.2		
——	4934.25				
36.02		2	2	Sharp.	35.90
37.51		2	2	Very diffuse.	
45.63		1.2	2	Diffuse.	
——	(4950.25)				
46.20		1	1		
53.34		1.2	1.2		
71.54		1.2	2		
——	4973.27				
76.54		1	1.2		
80.36		3.4	2.3		80.40
——	4981.92				
84.30		3.4	2.3		84.10
97.04		1	1.2	Diffuse.	
98.42		2	2		
5000.48		2.3	2	Diffuse. ⊙ line double.	
03.92		1	1.2		
10.22		1	1		
11.11		1.2	1.2	Diffuse.	
12.62		2	2	Sharp.	
17.75		3.4	2.3		17.45
18.50		2	2	Very diffuse.	
——	5020.21				
35.55		5	2.3		35.56
38.80		2	2		
42.35		2.3	2	Diffuse.	
49.01		2.3	2	Diffuse. Cr has 48.96, distinctly divided.	

Nickel λ	R.	i Co	i ⊙	Remarks	Thalén
5051.74		1	1.2	Very diffuse, ⊙ line double { 51.75 .85	
58.22		1	1		
——	5060.25				
80.16		1.2	1.2		
80.70		5	2.3		80.70
81.30		5	2.3	Diffuse.	81.56
82.55		2.3	2	Diffuse.	
——	5083 53				
84.27		4	2.3	Diffuse.	
88.74		1	1.2		
89.13		1	1.2		
94.61		1	1.2		
97.06		2	2	Diffuse.	
99.50		2.3	2.3	Sharp.	99.46
5100.13		3.4	2.3	Diffuse.	00.66
03.13		2	1.2		
——	5110.57				
15.55		4	2.3	Very sharp.	16.00
21.74		1.2	?		
25.39		2.3	2.3	⊙ line a close double.	
29.52		3	2.3		
30.55		1	1		
31.94		1.2	1.2	Diffuse.	
37.23		4	2.3	Very sharp.	37.91
——	5141.92				
42.96		3.4	2	Diffuse.	43.11
46.64		4	2	Diffuse.	46.81
53.43		2	2		
55.34		2	2	Diffuse.	
55.92		3.4	2.3	Diffuse.	56.21
58.20		1	1		
——	5167.57				
68.83		2.3	2		69.41
76.73		2	2		76.71
84.78		1.2	1.2		
86.80		1	1		
——	5188.95				
92.70		1	?		
97.40		1	1		
——	5198.89				
5216.72		1	1		
20.51		1	1		
——	(5227.40)				
68.59		1	1		
——	5270.49				
5371.64		2.3	2		
——	5379.77				
88.71		1	1		
92.68		1	1		
——	5397.34				
5411.50		2	1.2	Sharp.	
——	5415.42				

Nickel λ	R.	i Co	i ⊙	Remarks.	Thalén
5424.85		2	1.2		
——	5434.74				
36.10		2.3	1.2	Very sharp.	
62.71		2	1.2		
——	5466.61				
68.42		1	1		
77.13		5	3		77.20
95.20		1.2	1	Sharp.	
——	5497.73				
5504.50		1.2	?		
10.28		2.3	1.2	Sharp.	
——	5513.21				
53.97		2	1.2	Sharp.	
——	5555.11				
78.98		2.3	1.2		
——	5582.19				
88.12		2.3	1.2	Sharp.	
89.63		2	1	Diffuse.	
92.44		3.4	2	Sharp. ⊙ line a close double. Coincident with red component.	
94.00		3	1.2		
5600.29		2	1.2		
15.00		3	1.2	Sharp.	
——	5615.88				
25.56		3	1.2		
28.62		1.2	1		
37.32		2	1.2		
39.02		1.2	—		
42.08		1.2	1		
43.31		1.2	1	Diffuse.	
——	5645.83				
49.90		2.3	1.2		
64.28		2.3	1.2		
70.22		2	1		
——	5675.65				
82.44		3.4	1.2	Diffuse.	
95.22		3	1.2	Diffuse.	
——	5701.77				
5709.80		3.4	2		
12.10		3	2		
15.31		3	2	Also a Ti line.	
——	5715.31				
48.57		1.2	1.2		
54.86		3	2.3		
61.10		2.3	1.2		
——	5763.22				
96.35		1	1		
5805.45		2	2		
——	5806.95				
47.26		1	1.2		
58.03		2	2		57.72
——	5859.81				
93.13		2.3	2		93.22
——	5896.15				

As the last column of this catalogue shows, the number of lines which Thalén observed in the spectrum of the induction spark is quite small; still it is sufficiently large to afford a basis for estimating the accuracy of his measurements. If the differences between our wave-length values are formed it will be found that they have a wholly accidental character, and that the probable error[1] of one of Thalén's wave-lengths is:

From observations of the cobalt spectrum, $s_{,} = \pm 0.32$ tenth-meters.
From observations of the nickel spectrum, $s_{,,} = \pm 0.24$ tenth-meters.

Among the lines of cobalt there is one, λ 5359.4, for which the difference *H-Th* reaches the abnormally high value of -1.34 tenth-meters. If this exceptional case is excluded, then $s_{,} = \pm 0.26$ tenth-meters, a value which is in complete agreement with the probable error of the observations of the nickel spectrum, and with that of the observations of titanium already discussed. It would be difficult to find any observations made at that time which are comparable, with respect to accuracy, to the observations of Thalén.

The differences between my wave-lengths and those of Liveing and Dewar, in the ultra-violet part of the spectrum measured by both of us, run somewhat differently. They are positive almost throughout, corresponding to a systematic deviation which is in the mean

$$H - LD = + 0.12 \text{ tenth-meters, for cobalt,}$$
$$= + 0.19 \text{ tenth-meters, for nickel.}$$

Since, however the wave-lengths of Liveing and Dewar are referred to Rowland's earlier wave-length of the *D* lines, for which Bell subsequently found the correction $+ 0.06$ tenth-meters, it is necessary, in order to reduce the above differences to the wave-length system of my observations, to apply the correction $- 0.06$. Thus they finally become

$$H - LD = + 0.06 \text{ tenth-meters, for cobalt,}$$
$$= + 0.13 \text{ tenth-meters, for nickel;}$$

[1] The probable error of my own observations is included in these values; but since this hardly exceeds ± 0.02 tenth-meters, the above figures also give the probable error of Thalén's measures with reference to Rowland's scale.

or, taking the mean,

$$H - LD = +\ 0.10 \text{ tenth-meters.}$$

This agreement is certainly to be regarded as a very satisfactory one.

The existence of cobalt and nickel in the Sun's atmosphere is a fact which has long been established. It is at once apparent on comparing the third and fourth columns of the table. If we arrange the lines in groups, according to their intensity, we obtain the following table showing the number of coincidences and non-coincidences for each group:

COBALT.

i	Coinc.	Non-Coinc.
1–1.2	73	150
2–2.3	143	106
3–3.4	76	17
4–4.5	29	2
5– .6	5	0

NICKEL.

i	Coinc.	Non-Coinc.
1–1.2	118	34
2–2.3	114	11
3–3.4	45	2
4–4.5	22	0
5– .6	6	0

It will be seen that the lines of nickel, especially in the weaker classes, are represented in the solar spectrum with considerably greater completeness than those of cobalt. Thus, while 86.5 per cent. of all the observed nickel lines are represented by solar lines, the percentage for cobalt is only 54.3. If we exclude the weakest class of lines, on the ground that it is more likely than others to contain foreign lines due to impurities, the percentages become respectively 93 and 66, and the significant difference between the two metals in this respect therefore still remains. This seems to indicate that there is more

nickel than cobalt in the solar atmosphere. In order to test this supposition I have arranged the coincident solar lines in groups, according to their estimated intensities, giving for each group the number of coincidences and the percentage which it forms of the total number of coincidences.

i⊙	Co	Ni
1	120 = 37 p.c.	70 = 23 p.c.
1.2	74 = 22.5 "	96 = 31.5 "
2	84 = 25.6 "	77 = 25.2 "
2.3	31 = 9.4 "	40 = 13 1 "
3	15 = 4.6 "	9 = 3 "
>3	2 = 0.6 "	13 = 4.2 "

This table shows that of the coincident solar lines the weakest are represented more numerously by cobalt than by nickel, while for the stronger lines just the opposite is true. The assumption of a more intense absorption by nickel than by cobalt seems, therefore, to have some foundation in this fact, and since, on account of the approximate equality of their atomic weights, these two metals must exist in the Sun at the same temperature-level, the strongeı absorption on the part of the nickel vapor would represen a greater quantity of that substance.

Minor Contributions and Notes.

BENJAMIN APTHORP GOULD.

Benjamin Apthorp Gould was born in Boston, September 27, 1824. After his course in Harvard College, where he graduated with distinction in 1844, he went to Europe and studied under Gauss, Encke, Struve, Peters, Hansen and Argelander. As Dr. Chandler has recently pointed out,[1] the influence which he exercised from that time forward contributed in a marked degree to the building up of American astronomy. In 1852 he was placed in charge of the longitude determinations of the Coast Survey, where he remained until 1867. While engaged in this work he found time to organize the Dudley Observatory at Albany, and from 1855 to 1859 he not only directed this institution, but carried it on at his private expense. In the ten years that followed he published much valuable work, including a discussion of the places and proper motions of circumpolar stars, since used as standards in the Coast Survey and, after revision in 1861, in the American Ephemeris; a reduction of D'Agelet's observations; reductions of the greater part of the observations made at the United States Naval Observatory since its establishment; reductions of the observations made by the expedition to Chili to determine the solar parallax; determination of the difference in longitude of European and American stations, made with the aid of the Atlantic cable; and the first reductions of astronomical photographs — Rutherfurd's negatives of the Pleiades. He also determined the right ascensions of all stars to the tenth magnitude within one degree of the pole with a transit instrument at his private observatory in Cambridge.

In 1865 he determined to extend his observations to the stars of the southern hemisphere. The expedition, organized at first with private assistance, finally resulted in the establishment of the Argentine National Observatory at Cordoba. The *Uranometria Argentina*, the zone observations of stars between 23° and 80° south declination, and the independent series of meridian circle observations for the

[1] In an appreciative paper on the life and work of Dr. Gould published in *Science*, December 18, 1896, from which many of the facts in the present notice are derived.

General Catalogue of 32,448 stars remain as lasting testimonials to the great work accomplished by Dr. Gould and his assistants. While at Cordoba he also secured some 1400 negatives of stellar clusters, the measurement and reduction of which he had practically completed at the time of his death.

The *Astronomical Journal* was established by Dr. Gould in 1849, and continued until 1861, when he was forced to suspend its publication. Fortunately for American astronomy it became possible to reëstablish the *Journal* in 1885, since when it has appeared regularly. Devoted exclusively to the publication of original investigations, the *Astronomical Journal* has performed a great service for science in the United States. It is satisfactory to know that it will be continued under the able management of Dr. S. C. Chandler, assisted by Professor Asaph Hall and Professor Lewis Boss.

Dr. Gould's numerous services to science received richly deserved recognition from many learned societies. His sudden death on November 26, 1896, the result of a fall at his home in Cambridge, will be widely mourned.

PHOTOGRAPHIC STUDIES OF THE MOON AT THE PARIS OBSERVATORY.

In a series of papers[1] published in the *Comptes Rendus* at various times during the last two years, MM. Loewy and Puiseux have given an account of the researches in lunar photography which they have carried on with the aid of the great equatorial coudé at Paris. Some of these papers are devoted principally to a description of the instrument and its adjustment, others to general remarks on the subject of lunar photography and the difficulties which must be overcome in order to realize the full capabilities of the apparatus at their command. An interesting point in this connection is the method which they use for getting rid of the motion of the image in declination, by choosing for exposure (with the aid of a previously prepared table), times when the Moon's motion in declination is neutralized by the change of parallax. The rate of the driving clock is controlled by the observer, without stopping the clock, by means of a sliding weight on the pendulum. In some places the authors give the conclusions to which they have been led, by a study of their photographs, as to the nature and prob-

[1] *C. R.* 119, 130-135, 254-259, 1894; 121, 6-12, 79-85, 1895; 122, 967-973, 1896.

able origin of the characteristic features of the Moon's surface. The last published paper (*C. R.* 122, 967–973, 1896) contains a somewhat more elaborate statement of these views, which differ in a number of important particulars from those of other observers. They resemble in many respects the views of Suess.[1]

This paper, when presented to the French Academy of Sciences, was accompanied by the first six sheets of a new photographic atlas, the scale of which is approximately 1 : 1,300,000. The corresponding lunar diameter is about $2^m.6$, and the scale, therefore, considerably exceeds that of Schmidt's map (2^m). Since the diameter of the image in the focus of the equatorial coudé is $0^m.18\pm$, the map represents an enlargement of 14 or 15 times. The enlargement is, however, not quite the same for all the plates, and a scale for each sheet would have added materially to the usefulness of the atlas.

The beautiful plates are heliogravures, prepared from enlargements on glass of the same size as the plates themselves ($0^m.48$ by $0^m.58$). The process is an expensive one, but it yields the best results. It is said that the grain of the negatives is finer than that of the plates used in America, and this is probably the case, as, judging by the relation between aperture and exposure, the plates seem to be slower. It may further be noted that the great focal length (18^m) of the equatorial coudé makes it specially suitable for the purposes of lunar photography, since with a large image the granulation of the negative is relatively less important than with a small one. The impressive size and fine definition of the unenlarged image obtained with the equatorial coudé are well shown by the exquisite heliogravure of the half Moon which forms the first plate of the atlas.[2]

We may now consider the explanation of the lunar markings which is proposed by the authors, and which forms part of the text accompanying the sheets. Suess remarks in the paper already referred to, that no selenographic theory can be established if it is not admitted that the forces which are revealed to us by their effects on the Earth equally exert their action on the Moon, and that the crusts of the two bodies are composed of similar materials. This reasonable hypothesis is accepted by Loewy and Puiseux as the basis of their own theory. So far as the character of the crust is concerned, the principle of Suess

[1] *Sits. d. K. Akad. d. W. Wien*, February 1, 1895. English abstract in *Pub. A. S. P.*, No. 42, 7, 139–148, 1895.

[2] See also the Annual Report of the Observatory of Paris for the year 1895.

need not be too rigidly applied. An assumption of identity in the materials of the crusts of the two bodies would oblige us to regard the density of the Moon as uniform, since the density of the volcanic rocks of the Earth is about the same as the mean density of the Moon. The lunar crust may be supposed to consist of materials considerably lighter than the ordinary volcanic rocks of the Earth without affecting the reasonableness of the assumption. In any case, the adoption of the hypothesis rules out all but a limited number of possible explanations of lunar formations.

The theory of Loewy and Puiseux is a modified form of the volcanic theory, and their attention is first given to an inquiry into the possibility of present or past eruptive action. The principal arguments opposed to the volcanic hypothesis may be reduced to the three following: (1) the annular formations on the Moon are entirely distinct, by reason of their form and size, from all known craters on the Earth; (2) every volcanic eruption is necessarily accompanied by an abundant disengagement of gas and aqueous vapor; (3) the Moon has neither a liquid surface nor an appreciable gaseous envelope, and its surface features have not been modified by the circulation of water. These objections are considered by the authors, their conclusion being that the conditions necessary for volcanic action probably existed in the past, if they do not exist now; moreover, they do not necessarily imply the existence of an atmosphere of considerable refractive power. The ordinary cause of explosions is the presence of water at great depths, and on the Moon the quantity of imprisoned vapors must have been greater than on the Earth, by reason of the more rapid cooling of the surface.

The authors believe, however, that there is some evidence of the present existence of a lunar atmosphere. Bessel's negative result has been generally accepted, yet modern observations have invariably shown that the Moon's diameter deduced from occultations of stars is smaller than that obtained from meridian transits. If they say, the values given by the two methods were definitive, the reality of a lunar atmosphere would be proved; but they do not mention the fa that there are reasons why the two methods should give results which differ in the manner actually observed,—reasons which have no connection with the possible existence of an atmosphere. Irradiation, diffraction, and imperfect definition arising from a variety of causes, all tend to increase the measured diameter of a bright object. This has been well

pointed out in a recent article by Mr. Campbell.[1] The difference in question, which is only from 1" to 2", is very probably thus fully accounted for. A more reliable test for the presence of an atmosphere would seem to be its effect on the outline of a planet during an occultation, or on the direction of the Sun's limb during an eclipse, and in such occurrences the evidence is generally negative, although there are some exceptions on record. The question, however, is not an important one for the argument, since it may be conceded that an atmosphere probably existed under past conditions, even if there is none at the present time. An examination of all the conditions leads the authors to conclude on *a priori* grounds, that the Moon was once specially well fitted for the display of eruptive phenomena.

In framing their hypothesis MM. Loewy and Puiseux have used all the well-known data, and to a considerable extent, it would appear, data which they have obtained from a study of their own photographs. The facts which they regard as most significant are as follows:

"(1) The mountainous regions of the Moon are traversed for great distances by straight grooves (rills), in the course of which numerous eruptive funnels have been formed. (2) These rills, which are distributed in several parallel systems, have frequently served to limit the contour of the craters, and have therefore contributed toward giving them their polygonal shape. (3) The great craters have a tendency to occur in groups of two, three or four, arranged in certain definite directions which agree with those of the rills in the same region; (4) it is not rare to find them surrounded by a ring of secondary craters; the top of the rampart is a favorite place for the subsequent formation of eruptive funnels and centers of explosion. (5) When several craters overlap, the smallest is ordinarily the deepest, and is the only one which has a complete wall and a central mountain. (6) In the deepest craters the interior is generally studded with numerous hills grouped around a central mountain. If the bottom is less deeply depressed it appears as a plain, from which the central peak alone emerges. If it is still higher the central peak disappears, and the whole interior has a uniform aspect entirely similar to that of the seas. A final category is formed by annular forms without an interior depression, where the rampart alone exists, often incomplete and half submerged. (7) The great plains known as seas have in general a circular form, and are not distinguished from the largest craters except by their size. It is only

[1] "A Determination of the Polar Diameter of Mars." *A. J.*, No. 354, 15, 145.

in exceptional cases that their surface exhibits the cones, eruptive funnels and rills that are found in such great numbers on the high plateaus. Their outline is often marked by a fissure, either single or double, which forms the boundary between the plain and the mountainous regions. Veins, standing in slight relief, are seen traversing the surface of the plain, having, like the fissures, a tendency to run concentrically with the rampart. (8) The seas have in general a dark color, like the plains inside the great craters. The color of the plateaus is lighter. A coating of special whiteness covers the central peak in many of the craters. (9) The surface of the Moon is strewn with a large number of white patches. In the majority of cases these patches surround craters of small or moderate dimensions, and if the central opening should appear to be wanting, it may be said, with a probability almost amounting to certainty, that a different illumination will reveal its existence. All the craters in the same region are often surrounded by these white aureoles. Specially to be noted among these objects are the curious streaks which radiate from a small number of craters, and extend to enormous distances. (10) The divergent streaks have no effect on the relief of the regions which they traverse. They cross the plains and the mountains without inflection, and show no tendency to flow down the valleys."

Several interpretations of these facts present themselves as possible. The following are regarded by the authors as the most satisfactory:

"The rills are, as we have already explained,[1] the traces of the imperfect joining of floating masses, having their origin in an early period when a solid crust was forming on the Moon's surface.

"The seas, and likewise the great craters, are the result of successive sinkings due to the action of forces having various origins.

"The polygonal form of the great craters was determined by the preëxistence of the straight rills, which in many cases constituted lines of least resistance and acted as limits to the final sinking of the crust.

"The same cause determined the grouping and alignment of the craters in certain directions. The projecting ramparts and the central mountains indicate that the subsidence was preceded by a general elevation of the region occupied by a crater, and by the formation of a volcanic cone near the summit of the protuberance. The elevated

[1] *C. R.*, 121, 79–85, 1895.

veins which are found on the surface of the seas mark the course of ancient fissures filled by lava which solidified in obtrusion.

"The similar aspect of the seas and the flat interiors of the craters, the isolation or disappearance of the central peaks, indicate the partial invasion of the surface by lava which afterward solidified.

"The aureoles which surround the craters are deposited masses of volcanic cinders which were explosively projected. The divergent streaks resulted from the dispersion of these cinders to great distances under the action of variable atmospheric currents. The size and depth of the lunar craters have been regarded by various authors as irreconcilable with a volcanic hypothesis. There is, however, plenty of room for the belief that each great crater was not, as a whole, an eruptive opening, but that the space occupied by it was the theater of an intense volcanic activity, manifesting itself by a number of more or less large orifices. The testimony in favor of this view which is offered by all the facts relating to the aureoles and streaks seems to us absolutely decisive.

"The seas, more recently formed than the greater part of the craters, correspond to extensive sinkings of a crust already resistant, and capable of sustaining itself over a certain area. Their general arrangement reproduces with considerable fidelity that of the great depressions in the terrestrial crust, and notably that of the inland depressed areas which have been studied by geologists.

"The narrow fissures found to exist on the borders of the seas indicate concentric sinkings. Some of them appear to be rents in the soil caused by eruptive elevations."

Thus the authors have sought to refer all the characteristic and important features of the Moon's surface to a probable cause; and in doing so, they have found the basis for a chronological classification, which is given below.

"Taking as a point of departure the state of complete fluidity, we recognize as a well-marked first period that in which masses of scoria, agglomerated into fields of greater or less extent, appear upon the surface; these fields are often broken, and in cooling are subsequently reunited. The lines of junction and of rupture often remain, disposed according to a regular system which is clearly shown on our photographs.

"The formation of a continuous crust on the Moon marks the beginning of a second period, where the lava which accumulates at

certain points under the influence of the Earth's attraction or any other cause, no longer finds a free vent to the surface, and is obliged to create one. In an envelope still capable of offering moderate resistance, this tendency is revealed by the formation of cracks. The lava flows out by the way thus offered to the surface of the Moon. It soon solidifies, giving to the overflowed portions the aspect of a smooth plain.

"As time passes the crust becomes more solid; it opens only under the action of interior pressures powerful enough to raise it, by which swellings are produced, followed by depressions. This third period is that of the appearance of the great craters.

"At length elevations become exceptional and embrace areas more and more restricted. General sinkings, on the contrary, are still possible, and can extend over areas greater than the crust is capable of upholding without support. We are therefore led to distinguish a fourth period; that of a general sinking giving rise to the depressed areas known as seas.

"The existence of spots and streaks which cover indifferently the seas and the plateaus, the ramparts and the floors of the craters, incontestably proves the existence of a phase of activity more recent than the solidification of the surface of the seas. Hence there is room to consider a fifth period, in which, on account of the constantly increasing thickness of the crust, the most intense volcanic forces can only manifest themselves by temporary, though violent, eruptions, limited to orifices of small dimensions. These phenomena partly change the color of the surface without effacing the relief of its principal features.

"The white streaks issuing from definite centers radiate in all directions, and sometimes extend to enormous distances. Their recent origin is demonstrated by the fact that they leave absolutely intact the relief of the regions which they traverse, and their general appearance and character is evidence in favor of the former existence of a lunar atmosphere which it would seem difficult to confute."

Finally, the authors express the belief that it is not certain that the fifth period has entirely closed and that the era of absolute quiet has set in upon the Moon. The forms we see were probably produced when the thickness of the crust did not exceed ten or twelve kilometers —a thickness which is but a small fraction of the Moon's diameter. In the absence of all precise indications as to the age of these forma-

tions, we are permitted to regard general movements of the surface as still possible, and also such volcanic outbursts as have led to the formation of the great white streaks.

The selenographic theory here outlined resembles in many respects that of Suess, particularly in the important fundamental assumption of forces which are merely such as must have been active on the surface of the Earth, though modified in their action by the conditions peculiar to the Moon. There are, however, some important differences. According to Suess, the seas are "fusion hearths,"[1] formed by the remelting of the thin, partly solidified crust, and hence they represent one of the earliest stages in the formation of the surface; while their rocky walls are formed, not by a falling away of the crust on one side at an advanced stage of cooling, but by the pushing outward and crowding together of masses of slag at the rim of a great partially melted area. In the hypothesis of Loewy and Puiseux the formation of the seas is placed in the fourth period; in that of Suess, in what corresponds to their second.

The white rays or streaks have always been one of the chief selenographic puzzles, and every variety of explanation may be found in the great number of articles that have been written about them. The suggestion that they are volcanic ashes formerly ejected from craters has been previously advanced. Regarded in this aspect their most intractable feature is their straightness. Schaeberle supposed that they were straight and narrow for such great distances because there was no atmosphere to cause a deviation from the original plane of projection, but he was obliged to evoke the aid of an unknown extraneous force to account for their unsymmetrical distribution. According to W. H. Pickering, the rays are made up of smaller streaks, each of which proceeds from a minute crater. The component streaks are all tailed the same way, in consequence of atmospheric currents generated by eruption at or near the central crater, and condensation of the liberated vapors in a remote region. Suess regards the rays as due to bleaching of the surface rocks by acid vapors, which once escaped from orifices distributed along the line of original fissures. The late A. C. Ranyard thought they might be due to hoar frost, deposited from aqueous vapor escaping from such fissures as those just mentioned. These are a few examples of the more recent explanations.

If it is true, as some observers assert, that the eye can perceive with a small telescope details which cannot be photographed with a

very much larger one, the photograph must still be superior to eye observation for showing general features, and the relations between objects widely separated on the Moon's surface. If, further, there is any possibility (it would seem to be a small one) that volcanic force may again be called into play, the nature and extent of such changes in the surface as we may expect them to produce could be satisfactorily determined only by reference to photographs like those now being taken at Paris and Mt. Hamilton. But photographic maps of the Moon have been looked forward to so long, and have been discussed so often, that it is unnecessary to point out their various fields of usefulness. K.

REVIEWS.

Ueber Gesetzmässigkeiten in den Spectren festen Körper. F. PASCHEN. *Wied. Ann.* 58, 455–492, 1896.

UNDER this well-chosen title, Dr. Paschen has not only furnished abundant experimental evidence for thinking that the radiation of energy from heated solids obeys laws, but he has also discussed his observations with consummate skill and has shown us just what some of these laws are.

The statement of the problem which Dr. Paschen has set before himself may, perhaps, be most simply made as follows. The spectrum of a gas, when produced by any of the ordinary electrical means, is said to be described when the wave-length and intensity of each line is given. Considerations of temperature enter, so also those of pressure, but at present the all important factors are the distribution of intensity in the line, and the wave-length (or frequency) of the maximum intensity. This information concerning spark or arc spectra is, in general, obtained partly by the eye, partly by the photographic plate, and partly by the bolometer. When, however, the spectrum of a solid body is under examination, whether it be considered as a limiting gaseous spectrum in which all wave-lengths are represented, or as a gaseous spectrum of one single line widened out so as to cover the whole range of wave-lengths, its description is complete, in either case, only when, for each particular wave-length, we know the intensity of the radiation and the temperature of the source. And, for measurable temperatures, the one available instrument is the bolometer or radiomicrometer.

The accurate experimental determination of this intensity as a function of temperature and wave-length in solid bodies, the accurate description of these results in a single mathematical expression, and the comparison of observations with mathematical predictions may be said to be the threefold object of the work under rewiew. Dr. Paschen's spectro-bolometer, with its fluorite prism, and his skill in the use of this difficult instrument, are too well known to need description in these colums. The solids to be heated were spread in layers

upon sheet-platinum. The platinum was heated by an electric current. The temperature of the source was thus under easy control, and was varied from 117° C. to 1001° C. Temperatures were measured by means of a well calibrated Pt—Pt.Rh. thermo-pile. The experimental part of the work (not to mention the extraordinarily large number of errors which must be either eliminated or allowed for in bolometric work), hinges on the determination of two sets of curves. One of these expresses the intensity as a function of the wave-length, while the temperature of the source remains constant. This is called the "energy curve." The other expresses the intensity as a function of the temperature, while the bolometric strip remains fixed at one wave-length. This is called the "isochromatic curve." For the energy curve, the temperature is the variable parameter; for the isochromatic curve, the wave-length is the variable parameter.

The report of this investigation is so free from the padding which sometimes permits a reviewer to condense results that any fair summary of Dr. Paschen's results calls for a complete translation. Among these results the following are some of the most important:

First.—If the energy curves are plotted, using as coördinates, *not* the intensity, J, and the wave-length λ, but $\log J$ and $\log \lambda$, it is found that these curves are congruent—have the same form — for all temperatures. This congruence, which was predicted by W. Wien, proves to be an exceedingly happy fact; for it enables one not only to fill out the absorption gaps which are introduced into the curve by the carbon dioxide and water vapor in the atmosphere, but also to complete the entire energy curve when once a few points on it have been measured, reminding one of the classical feat which the palæontologist performs with a few bones of an unknown skeleton.

The formulæ which H. F. Weber, W. Michelson, and Köveslighety have proposed as descriptions of the energy curve are disposed of, courteously but decisively, on the ground of incompetence; while Wien's expression for the intensity is practically identical with that at which Paschen arrives by experiment, viz.,

$$J = \frac{c_1}{\lambda^a} e^{-\frac{c_2}{\lambda T}}$$

where T denotes the absolute temperature, while c_1, c_2, and a are constants.

Second.—The wave-length of maximum intensity, λ_m in any energy curve, varies inversely as the first power of the absolute temperature for which the curve is plotted. This experimental result is also a mathematical inference from Wien's expression. It is found, however, that the following expression

$$\lambda_m \, T^{0.9500} = 1866.5$$

represents the observations (for iron oxide, at least) still better than the hyperbolic curve.

Third.—So much for the *position* of the maximum intensity, λ_m If now we inquire concerning the *value* of the maximum intensity, J_m as dependent upon the temperature, the experimental result is summarized in the following equation:

$$J_m = C\,T^a$$

$$\text{where} \begin{cases} C = 3.519 \times 10^{16} \\ a = 5.6577 \end{cases}$$

This equation is to be carefully distinguished from the equation of energy curve. For iron oxide, then, the whole story is complete when the mean energy curve and the general values of λ_m and J_m (the two preceding equations) are given.

Fourth.—The *total* radiation is roughly proportional to the fifth power of the temperature. More exactly

$$\int J\,d\lambda = c''\ T^{4.708}$$

where c'' is not a function of the temperature.

Fifth.—The isochromatic curves are plotted for iron oxide at six different wave-lengths; when logarithmic coördinates are used, these curves also are shown to be congruent. And this proves to be a fact of great utility; for knowing a few points on any isochromatic curve it is possible to complete this curve, and thus to determine the temperature at which the *energy* curve has its maximum at the particular wave-length which serves as a parameter for this isochromatic. Knowing the temperature of the maximum one can then, by the eqnation given above, viz.,

$$J_m = C\,T^{5.6577}$$

evaluate this intensity without having either to produce or to measure a temperature which may be inconveniently high for present laboratory methods.

If space were of no consideration, it would be interesting to follow a special method of plotting the isochromatic curves by which they are congruent with the energy curves. We must also forego a description of the method by which the radiation of the shutter is allowed for; likewise the manner in which one plots the intensity per unit difference of frequency as a function of the frequency. Dr. Paschen points out that what is true of iron oxide is also true of the other solids which he has examined, the only change in the general equation occurring in the constants. One is at a loss to know which to admire the more, the manipulative skill that furnishes normal spectra in the infra-red with a prism and bolometer, or the masterly discussion which gives such elegant graphical and algebraic expression to the results. In any case, one is forcibly reminded of Professor Karl Pearson's contention that the so-called "exact sciences" have forever disappeared and have been replaced by "descriptive sciences." And physics may be said to be a descriptive science *par excellence*, since it speaks a language which is terse and clear beyond the dreams of any rhetorician. The completion of Dr. Paschen's investigation will be awaited with unusual interest. H. C.

Experimental Determinations of the Temperature in Geissler Tubes. *Phys. Rev.*, 4, 191–206, and *Wied. Ann.*, 59, 238–251, 1896.

When the history of the Geissler tube comes to be written, it is not unlikely that the last ten years of this century will stand out as an important period. For within this decade much definite information has been obtained, especially in the laboratories at Cambridge and Berlin, concerning the physical conditions under which electrical discharges occur in these tubes.

The investigation under review is an experimental determination of the local temperatures which prevail, inside the tube, during the passage of a constant current from a storage battery of 1250 volts. Incidentally Mr. Wood describes two neat experimental devices: one for using the Geissler tube as the bulb of an air thermometer, thus measuring the change in "average temperature" which results from the passage of the current; the other a delicate manometric tube for showing the extreme rapidity of the pressure variations (thermal changes) inside the tube when an intermittent current is employed.

The main part of the paper, however, is devoted to the investigation of the two following questions:

First.—At any one point in the tube, how does the temperature vary as a function of the current strength?

Second.—The current remaining constant, how does the temperature vary from point to point, as one passes from anode to cathode?

The first of these questions was answered by sealing a stationary bolometer in the tube and varying the current; while, for the second, Mr. Wood very ingeniously employed a Torricellian vacuum as a Geissler tube. This permitted him to use a movable bolometer arm carried on the upper end of a slender glass rod, running up through the mercury into the vacuum.

The chief results of the work are represented in several well chosen diagrams, which should be consulted by everyone interested. The most important of these results are two in number, viz.:

First.—The rise in temperature at any point in the tube, so far as can be detected by a bolometer wire $\frac{1}{80}^{mm}$ in diameter, is trifling, not exceeding 30° C. when a current of 3 milliamperes is used.

Second.—The distribution of temperature along the tube is that which one would predict if all the heat developed were "Joule heat." This is the assumption of Warburg; and the assumption is justified by Mr. Wood's results.

Taking due account of the more or less rapid changes brought about by conduction and convection, the distribution in this gaseous conductor appears to be exactly that which is met in the case of a solid composite conductor conveying a constant current, viz., the heat is developed most rapidly in those parts in which the fall of potential is most rapid.

In all other sources of intense luminosity we are so accustomed to find high temperatures that one finds it difficult, in the absence of conclusive experimental evidence to the contrary, to believe that there is not, *somewhere*, in the Geissler tube also a source of high temperature. Mr. Wood has taken the precaution to use continuous currents. But to what degree are these currents really "continuous" in a medium which is continually "breaking down" under electrical stress? Is it not possible that here also the "streaks" which Wüllner observed with the rotating mirror may also occur?

On the other hand, it does not appear either impossible or improbable that the supposition of E. Wiedemann may be correct, viz., that

the electromotive forces brought to bear upon the tube may put into rapid vibration the ether associated with the molecules of matter (*Aetherhüllen*) without, at the same time, essentially altering the translational kinetic energy of the molecules. It will be remembered that Professor Michelson has offered independent experimental evidence for thinking that the temperatures of the Geissler tube are low (ASTROPHYSICAL JOURNAL, 2, 251, 1895).

These questions demand for their answer apparently a finer grade of machinery than that employed by Mr. Wood; albeit his measures are doubtless the best that have ever been made. In using a bolometer wire only $\frac{1}{50}^{mm}$ in diameter the limit of the method has perhaps been nearly reached; for even if the diameter of the wire were of molecular dimensions, and yet large enough to convey a bolometer current, it would seem highly probable that the rapid changes in temperature which might be indicated by it could no longer be followed by any instrument now available.

If, as a matter of fact, the temperatures indicated by Mr. Wood's bolometer strip approach asymptotically those indicated by an indefinitely small wire, and if the current is not in some way the *immediate* cause of light then the conditions of luminosity in the Geissler tube would appear to be, in many ways, analogous to those which Dr. Huggins has suggested for nebulæ. In his presidential address (*Brit. Assoc.* 1891) he says:

"On account of the large extent of the nebulæ, a comparatively small number of luminous molecules or atoms would probably be sufficient to make the nebulæ as bright as they appear to us. On such an assumption the average temperature may be low, but the individual particles, which by their encounter are luminous, must have motions corresponding to a very high temperature, and in this sense be extremely hot.

"In such diffuse masses, from the great mean length of free path, the encounters would be rare but correspondingly violent, and tend to bring about vibrations of comparatively short period, as appears to be the case if we may judge by the great relative brightness of the more refrangible lines of the nebular spectrum.

"Such a view may perhaps reconcile the high temperature which the nebular spectrum undoubtedly suggests with the much lower mean temperature of the gaseous mass, which we should expect at so early a stage of condensation, unless we assume a very enormous mass; or

that the matter coming together had previously considerable motion, or considerable molecular agitation."

It would appear in keeping with the simple physical properties which gases exhibit, in contrast with liquids and solids, that the Geissler tube, so far from maintaining its old position as a veritable *terra incognita*, should shortly become perhaps the best understood of all sources of light. H. C.

THE RADIATIONS OF URANIUM AND ITS SALTS.

Sur diverses propriétés des rayons uraniques. HENRI BECQUEREL *Comptes Rendus*, **122**, pp. 501, 559, 689, 762, 1086; **123**, 855. See also a review by G. Sagnac, *Jour. de Phys.*, 3d series, **5**, 193–202 1896.

IN the above papers is given an account of the properties of certain radiations of uranium, and the various uranium compounds. These radiations were discovered by Henri Becquerel, in the early part of 1896, and are most interesting because they seem to be intermediate between the ordinary ultra-violet radiations of the arc or spark discharge, and the X-rays discovered by Röntgen.

The properties of the uranium radiations are briefly these, as observed by Becquerel:

The radiations are emitted by all known salts of uranium, and best of all by the element itself, even if kept in a dark space for six and more months. The intensity of the radiation, as measured by its photographic action, decreases slightly in this interval. It acts upon both dry and wet photographic plates.

The radiation is hardly perceptibly increased by exposure of the substance to magnesium light, the radiation from a Crookes' tube, or to daylight, but an intense illumination may increase the radiation slightly. Crystals of uranium nitrate which have been formed in darkness have the same radiating power as crystals exposed to light.

The radiations pass through most bodies more easily than do the X-rays. This is specially true of the metals. Lead, however, is quite opaque, and tin, fairly so. Water and most solutions, even metallic, are transparent.

The radiations are not homogeneous, as is shown by the fact that the absorption by a superposition of screens of copper and aluminium

or of platinum and aluminium is less than the sum of the absorptions produced by each separately.

The radiation can be reflected and refracted, as is proved by direct reflection from a steel mirror or from a concave mirror of tin, and by refraction through a crown glass prism. Total reflection can also be observed. The effects, however, are so irregular that no measurements of the index of refraction can be made.

The radiation can also be polarized, as appears from the fact that two superimposed crossed tourmalines are much more opaque than two whose axis are parallel.

The radiation discharges bodies which are electrically charged if it falls upon them. This is proved by means of an electroscope. If the radiation passes through a gas (*e. g.*, air or Co_2), the gas will itself discharge the charged electroscope if it be blown against it, even if there is no direct action of the uranium on the instrument.

Care was taken in all the experiments to guard against the action of any uranium vapors, and the effects are found to depend largely on the amount of uranium present, quite independently of the elements with which it may be in composition.

As noted above, these uranium radiations have properties in common with both light and X-rays; and this fact serves to strengthen the belief that X-rays are transverse ether-waves of extraordinary shortness. J. S. AMES.

JOHNS HOPKINS UNIVERSITY,
December 1896.

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1. *Anomalous Dispersion Curves of some Solid Dyes.* A. PFLÜGER. *Wied. Ann.*, 56, 412–432, 1895.
2. *On the Indices of Refraction of Solid Fuchsin.* B. WALTER. *Wied. Ann.*, pp. 394–396, 1896.
3. *On the Anomalous Dispersion of Absorbing Substances.* A. PFLÜGER. *Wied. Ann.*, 58, 670–672, 1896.
4. *On the Indices of Refraction of Metals at Different Temperatures.* A. PFLÜGER. *Wied. Ann.*, 58, 493–499, 1896.

DISPERSION curves of some of the strongly absorbent dyes had been given by Pulfrich, Ketteler and others, using alcoholic solutions, and E. Wiedemann, Lundquist and Merkel had given similar curves

for solid dyes obtained from measurements of elliptic polarization; the difficulty of interpreting the former results, and discrepancies among the latter, together with possible uncertainties in their theoretical deduction, led Pflüger to make the observations given in this first paper. He used solid prisms of very small angle (40″ to 140″) and a method substantially that which Kundt used in his work on the indices of refraction of the metals. Wernicke had previously used solid prisms of fuchsin, but of such large dimensions that no observations could be made inside the absorption bands. By using prisms of the very small angle above given Pflüger is able to observe the dispersion curve continuously from $\lambda = 6710$ to $\lambda = 4100$, though the image of his slit inside the strongly absorbent bands is, as would be expected, by no means sharp. That the great variation in the absorption from the thin to the thick side of his prism did not introduce any noticeable systematic error in his results seems to follow, as in Kundt's case, from the fact that he used prisms of varying angle, and found no systematic variation of the indices with the angle.

The substances examined were: fuchsin, cyanin, Hoffman's violet, magdaleroth, malachitegrün; and the most interesting results are: (1) inside the absorption bands the index of refraction decreases with decreasing wave-lengths; (2) fuchsin and Hoffman's violet gave values of the index less than unity, at the short wave-length end of their absorption bands; (3) inside the absorption bands the index varies with the angle of incidence (or, Snell's law does not hold).

The article of Walter gives a tabular comparison of indices of refraction of solid fuchsin for certain strongly absorbed wave-lengths, calculated on the one hand, from indirect observations before mentioned, by E. Wiedemann, Glan and others, and Walter, with those given by Pflüger in the preceding article. Walter calculated his values by means of Cauchy's theory from his observations of elliptic polarization, and there is a very close agreement between them and those of Pflüger, and very wide discrepancies between these and the others. In Pflüger's second paper he makes a similar comparison between his results and Walter's for "diamantgrün;" the agreement is again quite good inside the absorption bands, and poor outside. Walter's values for the weakly absorbed wave-lengths were obtained from total-reflection measurements, and why they should in both cases differ so widely from Pflüger's is not clear. Pflüger also calls attention to the values of indices less than and equal to unity, above mentioned; these and

similar results of Kundt's for some metals are of interest in connection with the view that the Röntgen rays are transverse ether vibrations of very short period for which all substances examined have indices equal to unity.

The fact that a number of the metals arrange themselves with respect to their indices of refraction in the same order as with respect to their electrical and thermal conductivities, led Kundt to an investigation of the temperature variation of these indices, to see if the same similarity held there. He found that the temperature coefficients of the indices were of about the same absolute magnitude but of opposite signs to the temperature coefficients of the conductivities. His results were not verified by later observers, notably Drude and Zeeman; Pflüger has therefore repeated Kundt's observations with greater care and he finds no measurable temperature variation of the indices of Ni, Au, and Fe. C. E. MENDENHALL.

On a New Photographic Method of Photometry and its Use in the Ultra-Violet. H. TH. SIMON. *Wied. Ann.*, 59, 91–115, 1896.

THE photometric method of Simon may be briefly outlined as follows: Two portions of a photographic plate are simultaneously exposed in exactly similar ways to light from two sources — the one the standard source, the other the light to be compared. The latter is then gradually weakened, and the plate at the same time uniformly moved so as to expose a new portion of its surface. Upon development that part of the plate exposed to the standard source will be uniformly darkened throughout its whole whole length, while the other portion will gradually diminish in density. At a certain point of the length the two halves will be of equal density; by knowing the extent to which the strong light has been weakened at this instant, its value in terms of the standard is directly obtainable. Of course this method is only applicable to the comparison of homogeneous lights of the same wavelength. The apparatus as devised and used by Simon consists of the following parts: (1) a spectrometer, having a quartz train, and in place of the eyepiece, a second slit and a device for moving the photographic plate past this slit. (2) The light-weakening apparatus, for which purpose the ordinary sectored disk is used, but so arranged that the apertures of the disk (of which there are three, of 60° each) can be gradually closed by a second disk — and this while the two disks are

rapidly rotating. (3) Connecting mechanism by means of which any given angular opening of the apertures of the disk is made to correspond to a definite position of the sensitive plate. The plates so exposed and developed have a dark line separating the two halves which are to be compared, and in order to avoid the difficulties of comparison which this introduces a special comparison device is used. This consists of an objective, bi-prism, and eyepiece, and has its objective end covered with a diaphragm containing two semi-circular apertures; it is so adjusted that one of the images, formed by the bi-prism, of aperture *a* is brought accurately opposite and in contact with an image of *b*. The two halves of the developed plate being placed in front of *a* and *b*, respectively, and moved along, the position of equal density can be found to within about $0^{mm}.6$. It is seen that this method assumes that the photographic action is the same for a given light time of exposure, whether that exposure is continuous or intermittent; previous observers have differed on this point—and it is probably not true at the limit of sensibility of a plate; but Simon seems to have justified the assumption for the conditions under which he worked, by comparing disks having the same total aperture, but having individual apertures of greatly different sizes. Under ordinary conditions the method is accurate to about 0.5 or 0.6 per cent. The method is also applicable to the measurement of absorption coefficients, and has been applied with quite satisfactory results to one case, which is given in the original paper, together with full details of adjustment.

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3. STARS AND STELLAR PHOTOMETRY.

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CHANDLER, S. C. Ephemeris of Long-Period Variables for 1897. Ast. Jour. No. 387, **17**, 17–20, 1896.

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The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

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THE

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THE ABSORPTION OF LIGHT AS A DETERMINING FACTOR IN THE SELECTION OF THE SIZE OF THE OBJECTIVE FOR THE GREAT REFRACTOR OF THE POTSDAM OBSERVATORY.[1]

By H. C. VOGEL.

THE extraordinary advances which technical science has recently made in the manufacture of glass for optical instruments, and especially for telescope objectives, extend not only to the production of very large and pure pieces for the latter purpose, but to the production of highly refrangible glass as free as possible from color.

At the technical laboratory at Jena varieties of glass have also been made, by the combination of which the secondary spectrum has been reduced to an almost imperceptible quantity, so that achromatic objectives of almost ideal perfection have actually been made and have come into use; but although the efforts which only two decades ago appeared to be hopeless—to produce kinds of glass which could be so combined—have thus been crowned with success, it was only too soon apparent that the kinds of glass used were not permanent when exposed to the air, as they soon became covered with an opaque film

[1] "Die Lichtabsorption als maasgebender Factor bei der Wahl der Dimension des Objectivs für den grossen Refractor des Potsdamer Observatoriums," *Sitz. d. K. Akad. d. W. Berlin* 46, 1219–1231, 1896.

which made the objective unserviceable. At present, therefore, progress in the direction of object glasses for large telescopes has extended only so far as this, that glass of admirable purity and of almost complete freedom from color is available for their manufacture.

Lenses as free as possible from color are especially desirable when the telescope is to be used, not only for direct observations, in which case the less refrangible rays are those chiefly concerned, but also for photographic purposes. For the otherwise excellent, but strongly yellow glass used by Fraunhofer, the limit, up to which an increase of the diameter of a photographic objective is profitable (a consequence of the increased absorption as the thickness is increased), is reached at a diameter of about 35^{cm} to 40^{cm}; whereas, in the case of the more recent kinds of glass, this limit is approached only at a diameter about three times as great.

Various factors existed for determining the construction of the large refractor designed for the Potsdam Observatory and for fixing the size of the objective. Although the situation of the Observatory, so far as the atmosphere is concerned, may be regarded as a favorable one for Central Germany, it nevertheless cannot be compared with that of observatories located at greater elevations, as, for instance, the observatory on Mount Hamilton. A telescope with a visually achromatized objective of a size similar to that of the later American instruments could be but seldom used to advantage under the atmospheric conditions met with here, and only in exceptional cases could it furnish observations which would have equal weight with those of other and more advantageously located observatories. Aside from this, the chief purpose of the Observatory, in accordance with which its activities are restricted as closely as possible to the domain of astrophysics, was to be kept in view; especially to be considered was the construction of an instrument by means of which it would be possible to continue the investigation of the motions of the heavenly bodies in the line of sight—an investigation in which this Observatory took the first successful steps, and the methods

for observing which it has established. A favorable condition of the atmosphere, however, has not so important an influence on spectrographic as it has in general upon visual observations.

In the case of the recent large telescopes, for instance that of the observatory at Pulkowa and that of the Lick Observatory, the objectives of which are achromatized for the visual rays, the imperfect achromatism of the objective becomes disagreeably evident in spectroscopic investigations not limited to the visible part of the spectrum, inasmuch as only a small part of the more refrangible regions of the spectrum can be investigated at a time. The extent of the part which can be so investigated decreases as the dimensions of the instrument, and the separation of the focal points of the actinic rays, thereby determined, increase. I here briefly give a few figures taken from a previous investigation[1] of mine concerning the achromatism of the Potsdam refractor of $29^{cm}.8$ effective aperture, and of the Vienna refractor of $67^{cm}.5$ effective aperture,[2] in order that the reader may recall the magnitudes of the quantities here considered:

Potsdam Refractor		Vienna Refractor	
Wave-length $\mu\mu$	Distance of the focal point from λ 486 $\mu\mu$	Wave-length $\mu\mu$	Distance of the focal point from λ 486 $\mu\mu$
690	$+\ 4^{mm}.2$	690	$+\ 2^{mm}.1$
610	$+\ 0\ .3$	610	$-\ 6\ .7$
530	$-\ 1\ .7$	570	$-\ 7\ .8$
470	$+\ 1\ .6$	470	$+\ 4\ .4$
430	$+\ 9\ .2$	430	$+20\ .7$
410	$+16\ .7$	410	$+31\ .1$

Attempts to unite more accurately the actinic with the optical rays by inserting a correcting lens in the cone of light have, so far as my knowledge goes, led to no satisfactory results.

These experiences led quite naturally to the conclusion that the objective of the great refractor should be achromatized for the actinic rays. An advantage in the mechanical construction

[1] *Monatsber. d. K. Akad. d. W. Berlin*, 1880, p. 438.

[2] *Publ. d. Astrophys. Obs. zu Potsdam*, IV Bd., I Th., p. 54.

of the instrument and the dome was gained at the same time: that of obtaining with the same aperture a large reduction in the focal length of the objective and also a large reduction in the diameter of the dome. There existed, however, the necessity for providing the large instrument with a guiding telescope of the same focal length.

. The intention at first was to devise an attachment for the large telescope (a system of lenses), by means of which a more complete union of the visual and actinic rays might be effected, and which might be thrown in or out at pleasure. However, since such a system, in order to be effective, would have to be composed of three lenses, and these, in order to obtain a fairly large field of view, could not be given a smaller diameter than 30^{cm} to 40^{cm}, various doubts arose as to the feasibility of the plan, having their origin partly in the not inconsiderable cost of the mechanical arrangement, as well as that of the lenses themselves. It was therefore decided to correct the large objective (achromatized for the chemically active rays) merely by means of a small double lens of Christie's construction, which should be introduced at a short distance from the focus when the large objective was required for spectroscopic investigations in the less refrangible parts of the spectrum, thus relinquishing any attempts to secure a considerable field of view. An experiment with such a correcting lens, which Steinheil of Munich computed and made for the photographically corrected refractor of 34^{cm} aperture and $3^{m}.4$ focal length, resulted quite satisfactorily.

Since for these reasons the great objective can be used to only a very limited extent for direct observation, the aperture of the guiding telescope was fixed at 50^{cm}, so that the guiding telescope itself must be regarded as a very effective instrument of observation; in fact, it exceeds in size all previously existing instruments in Germany.

In order to determine the size of the principal objective, a complete knowledge of the absorption of the kinds of glass to be used was especially necessary, since, as is well known, the absorption of the more refrangible rays, for which the objective

was to be achromatized, is greater than that of the less refrangible. The kinds of glass were, in accordance with the suggestion of Steinheil, who undertook the construction of the objective, ordinary light flint, O.340 (catalogue number of the technical laboratory at Jena), and ordinary silicate crown O.203, since these kinds of glass are easily obtained in large disks free from defects. No quantitative results as to the amount of absorption of these kinds of glass were at hand, and preliminary investigations were consequently undertaken at the Potsdam Observatory, with the result that 80^{cm} was adopted as the size of the objective. It is, therefore, larger than the objective of the Pulkowa Observatory, and will be the largest in Europe.

The great refractor of the Potsdam Observatory will accordingly consist of a double telescope, one tube having an objective of 80^{cm} aperture, achromatized for actinic rays, the other having an aperture of 50^{cm}, achromatized for visual rays. The focal lengths will be respectively 12^{m} and $12^{m}.5$, so that the ratio of the aperture to the focal length will be 1:15 for the principal instrument and 1:25 for the guiding telescope.

The investigations of the absorption of the kinds of glass decided upon for the objective were conducted chiefly by Professors Müller and Wilsing at this Observatory, and were concluded during the summer. Advantage was also taken of the opportunity to observe the effects of absorption of other kinds of glass, which are to be used for the spectrograph of the great refractor. Inasmuch as there are very few such determinations for new kinds of glass,[1] I believe that the publication of the following observations will be of somewhat wide interest, and that comparisons of different objectives given at the conclusion of this article will correct some erroneous notions which are frequently met with concerning the influence of absorption.

[1] I would here refer to: Conroy, "Some observations on the amount of the light reflected and transmitted by certain kinds of glass," *Phil. Trans.*, 180, 245, 1889. Dr. Krüss, "Über den Lichtverlust in sogenannten durchsichtigen Körpern," *Abh. d. Naturwissensch. Vereins zu Hamburg*, Bd. XI, Hft. 1. Eder and Valenta, "Absorptionspectren von farblosen und gefärbten gläsern," *Denkschr. d. K. Akad. d. W. Wien*, Bd. LXI, 1894.

I. DETERMINATION OF THE ABSORPTION IN THE VISIBLE PART OF THE SPECTRUM BETWEEN $\lambda 677^{\mu\mu}$ AND $\lambda 436^{\mu\mu}$.

The following observations were conducted by Professor Müller, with a Glan's spectrophotometer[1] somewhat modified by myself. It need scarcely be mentioned that every precautionary measure was taken in the investigations, and that only a cylindrical beam, and no diffuse light, was sent through the glass plates. The figures (the mean of four settings) give the intensity of the light, after passing through the glass, in terms of the incident light. The computation of the effect of reflection was made for each kind of glass by means of Fresnel's formula, $I = 1 - \left(\frac{n-1}{n+1}\right)^2$, where n is the index of refraction. It was sufficient for the purpose to take for the index of refraction that of the mean wave-length of the part of the spectrum investigated, and n for b_1 ($\lambda 518^{\mu\mu}$) was therefore taken. The effect of multiple reflections within the parallel plane surfaces of the glass has been neglected as insignificant. The reduction of the absorption to a thickness of the glass $a = 100^{mm}$ is obtained from the formula, $I_1 = I_0 K^{\frac{a}{\beta}}$, in which K is the quantity of light after having passed through the absorbing medium of thickness β, in terms of the incident light.

Flint glass O.340
Thickness $= 148^{mm}$
n for $b_1 = 1.5835$

λ	Measurements				Without reflection	For thickness of glass 100^{mm}
	Series I	Series II	Series III	Mean		
677	0.744	0.858	0.862	0.821	0.912	0.939
580	0.719	0.783	0.726	0.743	0.825	0.878
535	0.667	0.880	0.793	0.780	0.866	0.907
503	0.804	0.735	0.697	0.745	0.827	0.880
477	0.819	0.715	0.705	0.746	0.828	0.880
455	0.652	0.705	0.711	0.689	0.765	0.834
436	0.492	0.493	0.542	0.509	0.565	0.680

[1] *Monatsber d. Akad.*, März 1877.

Flint glass O.102
Thickness = 100mm
n for b_1 = 1.657

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
677	0.695	0.704	0.700	0.794	0.794
580	0.718	0.745	0.731	0.829	0.829
535	0.720	0.704	0.712	0.808	0.808
503	0.688	0.689	0.689	0.782	0.782
477	0.603	0.632	0.617	0.700	0.700
455	0.615	0.553	0.584	0.663	0.663
436	0.544	0.453	0.499	0.566	0.566

Flint glass O.93
Thickness = 114.8mm
n for b_1 = 1.632

λ	Measurements					Without reflection	For thickness of glass = 100mm
	Series I	Series II	Series III	Series IV	Mean		
677	0.878	0.771	0.910	0.763	0.830	0.935	0.943
580	0.777	0.818	0.824	0.741	0.790	0.890	0.903
535	0.699	0.777	0.743	0 844	0.766	0.863	0.879
503	0.818	0.693	0.736	0.786	0.758	0.854	0.871
477	0.724	0.824	0.744	0.852	0.786	0.885	0.899
455	0.707	0.737	0.669	0 668	0.695	0.783	0.807
436	0.584	0.551	0.564	0.713	0.603	0.679	0.714

Crown glass O.203
Thickness = 141.5mm
n for b_1 = 1.521

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
677	0.848	0.738	0.793	0.865	0.903
580	0.730	0.778	0.754	0.823	0.872
535	0.770	0.804	0.787	0.859	0.898
503	0.784	0.723	0.754	0.823	0.872
477	0.706	0.773	0.740	0.807	0.860
445	0.666	0.723	0.695	0.758	0.822
436	0.701	0.650	0.676	0.738	0.806

Crown glass O.598
Thickness = $102^{mm}.5$
n for b_1 = 1.519

λ	Measurements			Without reflection	For thickness of glass = 100 mm
	Series I	Series II	Mean		
677	0.824	0.747	0.786	0.857	0.860
580	0.768	0.723	0.746	0.814	0.818
535	0.810	0.634	0.722	0.787	0.792
503	0.720	0.694	0.707	0.771	0.776
477	0.701	0.704	0.702	0.766	0.771
455	0.721	0.681	0.701	0.765	0.770
436	0.832	0.623	0.727	0.793	0.797

Observations in the blue at λ $436^{\mu\mu}$ were difficult with petroleum light on account of the feeble intensity of this part of the spectrum, and since my eye is very sensitive to the more refrangible rays of the spectrum, I have repeated these observations, and at the same time have also made a few observations in the brightest part of the spectrum. I give here the values obtained, which agree very well with those found by Professor Müller.

Flint glass O.340

λ	Measurements				Without reflection	For thickness of glass = 100mm
	Series I	Series II	Series III	Mean		
580 } 535 }	0.770	0.708	....	0.739	0.821	0.875
436	0.567	0.494	0.552	0.538	0.597	0.706

Flint glass O.102

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
580 } 535 }	0.669	....	0.669	0.759	0.759
436	0.470	0.485	0.478	0.542	0.542

Common glass O.203

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
580 } 535 }	0.734	....	0.734	0.801	0.855
436	0.648	0.606	0.627	0.684	0.765

Common glass O.598

λ	Measurements			Without reflection	For thickness of glass = 100mm
	Series I	Series II	Mean		
580 } 535 }	0.741	....	0.741	0.808	0 812
436	0.593	0.595	0.594	0 648	0.655

2. DETERMINATION OF THE ABSORPTION OF THE MORE REFRANGIBLE RAYS BETWEEN λ $434^{\mu\mu}$ AND λ $375^{\mu\mu}$.

Before entering upon the more special parts of the investigation I must state, with reference to the properties of glass in general, that the absorbing power does not increase uniformly with the decrease in the wave-length; that rather an approximately constant effect is to be observed over large sections of the spectrum, and that the increase of the absorption takes place *per saltum*, as in the vicinity of the Fraunhofer lines G and H. The sudden and total disappearance of light of a certain wave-length with a certain thickness of glass is thus explained. For example, light flint glass of 10^{cm} to 15^{cm} thickness cuts off all light whose wave-length is less than $376^{\mu\mu}$. In the case of heavy flint O.102 a sudden and very marked decrease in the intensity of the transmitted light may be observed in the neighborhood of H. The spectrum may be followed a short distance beyond K, but it is excessively weak, and is then once more suddenly broken off. These observations agree with those of Eder and

Valenta,[1] who, with a thickness of glass of only 1^{mm} have been able to observe a similar, quite sudden falling off in intensity with most of the glasses investigated by them. Corresponding to the smaller thickness of glass, a total extinction of light did not occur until the point $\lambda\ 330^{\mu\mu}$ was reached.

It further appeared that flint O.340 of about 15^{cm} thickness produced two absorption bands. The middle of the one, a very weak and diffuse band, has a wave-length of $437^{\mu\mu}$, the middle of the other, a more sharply defined and quite conspicuous band, has a wave-length of $418^{\mu\mu}.6$. The width of the latter corresponds to a difference of wave-length equal to $3^{\mu\mu}.5$. The second absorption band also appeared in the spectrum when the light was passed through a plate of crown glass O.203 of about 14^{cm} thickness, but it appeared to be less strong. The heavy flint O.102 gave no absorption bands.

The determination of the absorption for certain places in the more refrangible parts of the spectrum by means of photography was beset by great difficulties arising from the fact that, according to recent investigations in photographic processes where the darkening of the plate is produced, not by the light directly, but by a process of development, a great difference exists between the resulting degrees of darkening and the product of the time and intensity concerned in their production. With the same exposure the photographic darkening does not increase proportionally to the intensity, but more slowly, and the deviation from such a law is different for plates of different manufacture. In order to deduce the intensity from equal darkenings, the times of exposure being known, the departure from the law, $It = C$, must be especially obtained for each plate, which in practice leads to difficulties scarcely to be surmounted.

Professor Wilsing has attempted to overcome this difficulty by limiting himself to the comparison of intensities differing but little from one another with equal times of exposure, so

[1] "Absorptionsspectren von farblosen und gefärbten Gläsern," *Denkschr. d. K Akad. d. W. Wien*, Bd. LXI, 1894.

that the measurements are based on the axiom that equal intensities produce in the same time equal darkenings. By measurements with Nicol prisms the reduction of two intensities, differing by any desired amount, to the same intensity, was made in accordance with the principle of Zöllner's photometer, and the photometric determinations in the more refrangible part of the spectrum differ, therefore, from those made by spectrophotometric means in the less refrangible part, in this respect only,—that the plate sensitive to light takes the place of the eye.

A more detailed presentation of the method pursued and the precautionary measures taken in carrying out the observations will be given by Professor Wilsing in the *Astronomische Nachrichten.* I here limit myself to pointing out their principal features, merely adding thereto the remark, with reference to the practical carrying out of the work, that the photographs were taken on bromide of silver gelatine plates with a small spectrograph which is frequently used, in combination with the photographic refractor of the Observatory, for photographing star spectra. It was found that a difference of 5 per cent. in the intensity could be recognized.

The results of measurements given in the following table are arranged and reduced in the same way as those given on pages 80 and 81. For computing the loss by reflection the index for h (λ 410$^{\mu\mu}$) was taken.

Flint glass O.340
Thickness = 148^{mm}
n for $h = 1.601$

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.389	0.434	0.569
(419)	(0.240)	(0.268)	(0.411)
400	0.435	0.486	0.614
390	0.280	0.313	0.456
375	0.221	0.247	0.388

The figures enclosed in brackets refer to the absorption band.

Flint glass O.102
Thickness = 100^{mm}
n for $h = 1.682$

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.439	0.502	0.502
400	0.405	0.463	0.463
395	0.146	0.167	0.167
390	0.022	0.025	0.025

Crown O.203
Thickness = $141^{mm}.5$
n for $h = 1.532$

λ	Measurements	Without reflection	For thickness of glass = 100^{mm}
434	0.515	0.564	0.667
(419)	(0.455)	(0.498)	(0 611)
400	0.546	0.598	0.695
390	0.426	0.466	0.583
375	0.426	0.466	0.583

The figures enclosed in brackets refer to the absorption bands.

I have attempted to determine the absorption effect of the glass for the more refrangible rays in another way,—by exposing sensitive paper (chloride of silver) to the sunlight both directly and after it had passed through the glass to be investigated, and then determining the degree of darkening by means of a scale which was produced by successive exposures to light. The comparison was made in yellow light, since it was not permissible to fix and tone the papers. Bunsen and Roscoe[1] have shown that, within very wide limits, equal products of intensity of light and time of exposure represent equal darkenings of chloride of silver paper. I had formerly used the method to advantage in determining the diminution of light from the center to the limb of the Sun's disk,[2] and I have now

[1] *Pogg. Ann.*, 117, 529 *et seq.*
[2] *Berichte d. K. d. W.*, Leipzig, July 1872.

verified my conclusion that by making a suitable choice of the time of exposure it was possible to attain a quite high degree of sensitiveness and to recognize a difference of intensity as small as 5 per cent.

From a large number of observations, in which not only the absorbing effect of each of the glasses separately was determined, but also the absorption of the different glasses relatively to one another, I have deduced the following results, which relate to rays that affect chloride of silver paper, *i. e.*, rays of the spectrum extending from G into the ultra-violet and having a maximum effect between *h* and H.

Kinds of glass	d	I_1	I_2	I_2 for d = 100mm
Flint O.340	148.0	0.346	0.386	0.526
Flint O.102	100.0	0.247	0.282	0.282
Flint O.93	114.8	0.270	0.306	0.356
Crown O.203	141.5	0.432	0.473	0.589
Crown O.598	102.5	0.547	0.610	0.604

Here d is the thickness of the glass in millimeters, I_1 the intensity, in terms of the incident light, of the light after having passed through a thickness of the glass plate equal to d, I_2 the intensity after allowing for the loss due to reflection, for the calculation of which, instead of the values for n which have been given, 1.654 is taken for Flint O.93 and 1.529 for Crown O.598.

In order to form an idea of the difference between the absorbing effect of the glass in visual observations and in photography, the preceding determinations of the absorption for certain definite kinds of rays must be combined, with reference to the power of the corresponding rays to affect respectively the eye and the photographic plate. For the less refrangible rays, which are chiefly concerned in direct observations, the mean may at once be taken of Professor Müller's observations combined with my own; since most of the observations are in the brightest part of the spectrum, and by forming the mean the distribution of light with reference to intensity is

sufficiently taken into account. For the two kinds of glass which are to be used for the objective, the following values were obtained for the intensity of the light after having passed through a thickness of 100^{mm}, in terms of the incident light:

0.84 for Flint O.340 and
0.85 for Crown O.203

In determining the absorption for the photographic rays I have assumed that the widespread bromide of silver gelatine plates are used. Their sensitiveness begins at F and extends far into the ultra-violet, and has a maximum between H_γ and H_δ. I take from the preceding investigations the following values from which to obtain a mean:

λ	Flint O.340	Crown O.203
$455^{\mu\mu}$	0.83	0.82
436	0.69	0.79
434	0.57	0.67
400	0.61	0.70
h — H	0.53	0.59
390	0.46	0.58
	Mean 0.615	Mean 0.692

Since the kinds of glass intended for the objectives of the Potsdam refractor are those which are generally preferred for large instruments, and the glass of the laboratory at Jena is coming into more extended use, the following table, which was computed on the basis of the values deduced above, will be of practical importance:

Thickness of objective in cm	Intensity of the transmitted in terms of the incident light			
	With allowance for absorption only		With allowance for absorption and reflection	
	Visual rays	Actinic rays	Visual rays	Actinic rays
4	0.93	0.84	0.77	0.69
6	0.90	0.77	0.75	0.63
8	0.87	0.71	0.72	0.58
10	0.84	0.65	0.70	0.53
12	0.82	0.60	0.67	0.49
14	0.79	0.55	0.65	0.45
16	0.76	0.50	0.63	0.41
18	0.74	0.46	0.61	0.38
20	0.71	0.43	0.59	0.35
22	0.69	0.39	0.57	0.32
24	0.67	0.36	0.55	0.29
26	0.65	0.33	0.53	0.27
28	0.62	0.30	0.52	0.25
30	0.60	0.28	0.50	0.23
32	0.58	0.25	0.48	0.21
34	0.56	0.23	0.47	0.19
36	0.55	0.21	0.45	0.18
38	0.53	0.20	0.44	0.16
40	0.51	0.18	0.42	0.15

The total thickness of the objective may, for the purpose of calculation, be taken at one-sixth or one-seventh of the diameter.

From the preceding table it follows that for the large objective of the new Potsdam refractor of 80^{cm} aperture, and of an assumed thickness of 12^{cm}, the loss of the actinic rays by absorption is approximately 40 per cent.; by both absorption and reflection 51 per cent. The ratio of the intensity of the transmitted light to that of the incident is 49:100.

To compare this with the objective of the Institute's photographic refractor of $34^{cm}.4$ aperture and 5^{cm} thickness, the ratio of the light-gathering power of the objectives is computed by multiplying the ratio of the squares of their apertures by the ratio of the amounts of transmitted light, expressed in terms of the same unit; that is $\frac{(80)^2}{(34.4)^2} \cdot \frac{49}{66} = 4$. The images of stars at the focus are therefore four times as bright for the

objective of 80^{cm} diameter as for the objective $34^{cm}.4$ in diameter, which corresponds to a gain of 1.5 stellar magnitude. A comparison with the Schröder refractor of the Observatory of $29^{cm}.8$ aperture, with which the determination of the motion of stars in the line of sight down to a magnitude of 2.5 was made, gives a much more favorable result. It may be assumed that with the objective of 80^{cm} aperture at least two additional magnitudes will be added to the range of observation. The number of stars whose motion can be investigated with the same precision as heretofore will be increased eightfold, or to about 400.

In spectroscopic investigations in the less refrangible part of the spectrum the intervention of a correcting lens becomes necessary, and this involves a still greater loss of light which can, however, scarcely be estimated at more than 20 per cent., since the compound lens will at most be about 20^{cm} in diameter and 4^{cm} thick, and the component lenses can be cemented together. Nevertheless, in consequence of the much smaller absorption for the optical rays, the gain of light of the large objective in comparison with that of the Schröder refractor will still be 1.8 magnitudes.

I may here also make a comparison in another direction, and will answer the question, "What advantage would be obtained by the use of a still larger objective, for instance one of 100^{cm} aperture?" If the thickness of the objective be taken as 15^{cm}, the result for the chemical rays is $\frac{100^2}{80^2} \cdot \frac{43}{49} = 1.43$, corresponding to a gain of 0.3 to 0.4 magnitude; a gain which is disproportionate to the very heavy cost of the objective and mountings.

Finally, I may give a comparison of the photographic refractor of $34^{cm}.4$ aperture, for which the ratio of aperture to focal length = 1 : 10, with the large objective of 80^{cm} aperture, with respect to the images which they form of objects that are not points. Here the ratio of aperture to focal length is chiefly concerned. Let V be this ratio, and let quantities relating to the large objective be represented by capitals, and those of

the small objective by small letters of the alphabet. Then

$$\frac{h}{H}=\frac{i}{I}\left(\frac{v}{V}\right)^2,$$

where I is the intensity of the transmitted light in terms of the same unit. The result is

$$\frac{h}{H}=\frac{66}{49}\cdot 1.5^2=3.$$

The brightness of the image per unit of surface for the smaller objective with relatively short focal length is therefore three times as great as for the large objective. The images in the focal plane of the latter have, however, twelve and one-half times as large an area.

THE SPECTRUM OF ζ PUPPIS.

By Edward C. Pickering.

The announcement was made in *Circular* No. 12 that the spectrum of the star ζ Puppis contained, in addition to the usual series of lines due to hydrogen, a second series of rhythmical lines. A remarkable relation exists between these two series, from which it appears that the second series, instead of being due to some unknown element as was at first supposed, is so closely allied to the hydrogen series, that it is probably due to that substance under conditions of temperature or pressure as yet unknown. The wave-lengths of the lines of hydrogen may be computed by the formula $\lambda = 3646.1\frac{n^2}{n^2-16}$ which is the formula of Balmer, slightly modifying the constant term so that the standard wave-lengths of Rowland shall be represented, and substituting $\frac{1}{2}$ n for m. The wave-lengths of the lines of hydrogen may be determined by this formula if we substitute for n the even integers 6, 8, 10, 12, etc.

In the annexed table the values of n, the designations of the corresponding lines of hydrogen, their computed wave-lengths, their observed wave-lengths, and the observed minus the computed values are given in the first five columns. If now we substitute for n the odd integers 5, 7, 9, 11, etc., we obtain the wave-lengths of the second series of lines in the spectrum of ζ Puppis, as is shown in the second part of the table. The sixth column gives the value of n, the seventh the corresponding computed wave-length, and the eighth and ninth the wave-lengths of the lines in ζ Puppis as derived from two series of measures. Miss A. J. Cannon has found that the same series of lines occurs in the star 29 Canis Majoris (*H. P.* 1380) whose position for 1900 is R. A.$=7^h\ 14^m.5$, Dec. $=-24°\ 23'$. As this star has the magnitude 4.8, only three lines of the series are measurable in the photographs so far taken, but, unlike ζ Puppis,

many additional lines are present. Measures of the lines common to ζ Puppis are given in the tenth column of the table and the observed minus the computed values for the two stars are given in the last three columns.

n	Des.	Comp.	H	O—C
4	--	∞	—	....
6	$H\alpha$	6563.0	6563.0	0.0
8	$H\beta$	4861.5	4861.5	0.0
10	$H\gamma$	4340.6	4340.7	—0.1
12	$H\delta$	4101.9	4101.8	+0.1
14	$H\epsilon$	3970.2	3970.2	0.0
16	$H\zeta$	3889.2	3889.1	+0.1
18	$H\eta$	3835.5	3835.5	0.0
20	$H\theta$	3798.0	3798.1	—0.1

n	Comp.	ζ	ζ	29	ζ	ζ	29
5	10128.1	.....	.....	.....	.....	.....	.....
7	5413.9	.....	.....	.....	.....	.....	.....
9	4543.6	R	R	R	.....	.....	.....
11	4201.7	4199.2	4201.6	4201.1	—2.5	—0.1	—0.6
13	4027.4	4027.1	4026.5	4025.4	—0.3	—0.9	—2.0
15	3925.2	3924.6	3924.9	.....	—0.6	—0.3	.....
17	3859.8	3858.7	3858.6	.....	—1.1	—1.2	.....
19	3815.2	3814.7	3817.2	.....	—0.5	+2.0	.....
21	3783.4	.....	3783.4	.....	.....	0.0	.....

The wave-lengths here given depend upon the lines of hydrogen and were determined from them by a form of graphical interpolation. The interval between $H\beta$ and $H\gamma$ is so great that the errors of interpolation are large for lines in that part of the spectrum. These errors are still greater in the approximate measures given in *Circular* No. 12, although the results there given for the five lines of the series of shorter wave-length than $H\gamma$ agree closely with those given above. Comparing the spectrum of ζ Puppis with the spectra of other stars, it appears that the four lines between $H\gamma$ and $H\beta$ probably coincide with the lines having wave-lengths 4472, 4544, 4633, and 4688. The first of these lines is very faint and appears to coincide with the

principal line distinguishing stars of the Orion type. The second line is well marked and is the line computed above when $n=9$. The third and fourth lines are bright and coincide with the principal lines in spectra of stars of the fifth type. These four lines are also present in 29 Canis Majoris. Several of the lines in the above table appear bright in stars of the fifth type. Thus in *H. P.* 1311 the lines for which n equals 8, 9, 10, 11, 12, 13, and 14 are bright. In γ Velorum these lines are also present, some being bright and some dark. The line for which $n=7$ is one of the most conspicuous in the visual spectra of stars of the fifth type. Its wave-length has been found by Campbell to be 5412.4, which agrees closely with the computed value 5413.9. He also finds the line 4540, which is probably identical with the line for which $n=9$. From photographs recently taken at Arequipa, but not yet received at Cambridge, it is expected that the wave-lengths of all these lines can be accurately determined.

January 12, 1897.

ON THE SPECTRUM OF ζ PUPPIS.

By H. KAYSER.

THE Harvard College Observatory *Circular* No. 12 contains a very interesting notice by Professor Pickering on the spectrum of ζ Puppis. Besides some bright lines it shows the hydrogen series and a series of lines hitherto unknown with the wave-lengths 3814, 3857, 3923, 4028, 4203, 4505. I think this series is of the highest interest, because it seems probable to me that we have here another hydrogen series. That the lines form a series was remarked also by Professor Pickering, and he finds that they are represented approximately by the modified formula of Balmer: $\lambda = 4650 \frac{m^2}{m^2 - 4} - 1032$, where m has the value 5 for the last observed line.

After seeing Professor Pickering's *Circular*, I immediately calculated the reciprocals of the wave-lengths and their differences. With the aid of the table given by Kayser and Runge ("Ueber die Spectren der Elemente," *Abhand. d. K. Akad. d. W. Berlin*, 1891, p. 65) it became evident that the last line must really have the number 5, so that it corresponds to the hydrogen line 4342. In plotting on the scale of frequencies the spectrum of hydrogen and the new lines of ζ Puppis, it appears that the lines of the two series lie nearer and nearer together as the order of the lines gets higher. It therefore seems that the ends of the two series would nearly coincide. Now Runge and myself have found that in the spectra of all the elements, where series could be found at all, there were two series ending at nearly the same place. In our formula $\frac{1}{\lambda} = A - Bm^{-2} - Cm^{-4}$ this is expressed by the fact that for the two series of every element A has nearly the same value. Besides these two series the alkalies have a third series, named by us the principal series, the lines of which are situated high in the ultrale-viot compared

with the other two series. Hydrogen has been so far the only element with a single series, and as the principal series contains the most intense lines of every element, it was generally thought that the hydrogen lines were the principal series. But I was never convinced of it: as with decreasing atomic weight all the series recede to shorter wave-lengths, and as the principal series of lithium ends below λ 2300, one would expect to find the principal series of hydrogen in parts of the spectrum hitherto photographed only by Schumann. But if the known series were not the principal series, we should expect to find another series ending at nearly the same point, with lines a little less intense but sharper. Now these conditions are fulfilled by the new series. Professor Pickering's photograph shows very well that every new line is weaker and sharper than the corresponding hydrogen line. The old hydrogen series is represented by the formula $\frac{1}{\lambda} = 27430 - 109721\, m^{-2}$, the new series by the approximate formula $\frac{1}{\lambda} = 27559 - 134054\, m^{-2}$. (I have calculated the constants only by the first and last lines; the method of least squares would, of course, give a closer approximation.) For the two series of lithium the corresponding constants are 28587, 109625, and 28667, 122391. I think this comparison shows that it is not improbable that Professor Pickering has found a new series of hydrogen, not the indication of a new element.

That this series has never been observed before, can perhaps be explained by insufficient temperature in our Geissler tubes and most of the stars.

BONN, Jan. 2, 1897.

ON THE SPECTRA OF HEAVY AND LIGHT HELIUM.

By J. S. AMES and W. J. HUMPHREYS.

SOON after helium was discovered by Professor Ramsay, it was suspected by several spectroscopists that the gas discovered was not pure, but a mixture. Crookes and Lockyer, both, based their opinions on observed irregular changes in the spectrum, but Runge and Paschen, as the result of a most interesting research, brought forward evidence which seemed quite conclusive in favor of the belief that the new gas derived from clèveite was a mixture of two "elementary" gases. It had been shown by Kayser and Runge that in the spectra of many elements there were three series of lines, each series having definite characteristics; and, so, when Runge and Paschen showed by a most elaborate investigation that in the spectrum of cléveite gas there were two independent sets of series, each set including the three characteristic and well-known series, strong evidence was afforded in favor of two elements being present in clèveite gas. Other evidence was also given, partly spectroscopic, partly chemical. One set of series of lines appears much more frequently in the chromosphere of the Sun than does the other; again, after diffusion through a porous plug, one set of series was much weaker than in the natural gas. More recently, in a paper by Ramsay and Collie, in the *Proc. R. Soc.*, **60**, 206, the authors show that by a process of diffusion, many times repeated, it is possible to separate helium gas into parts of widely different densities. In one experiment they obtained gases differing in density in the ratio of five to six.

With the spectroscope at their command, Ramsay and Collie were unable to detect any differences between the spectra of the heavy and the light helium; and it is through the kindness of Professor Ramsay that we have had placed at our disposal various specimens of heavy, light, and ordinary helium; so that their spectra might be studied by means of the instruments of

great dispersion in use in the physical laboratory of the Johns Hopkins University.

The tubes which we have examined are marked as follows:

1. Helium and argon.
2. He. II., Ap. 27, 95. W. R.
3. Samarskite, heaviest. Contains air.
4. Samarskite, lightest.
5. Residue from 400^{cc} He. from Samarskite, after at least ten diffusions.

In addition to these we have studied the spectra of two helium tubes which were filled by Professor Ramsay in previous years, and of a third belonging to Professor Remsen, which had been filled with helium, prepared from Samarskite by Professor E. C. Franklin, of the University of Kansas. The spectra were obtained by means of a concave grating, six inches wide, having 15,000 lines to the inch, and a radius of curvature of twelve feet. Both eye and photographic measurements were taken, the discharge was passed both with and without spark-gap, with both large and small current; and *in no case were there any differences observed between the spectra of the various tubes.* Most of the photographs were taken so as to include w.-l. 3600–5030; for in this space there are lines of all the six series observed by Runge and Paschen. The character of the lines, the relative intensities, and the entire appearance of the spectra are in all cases the same, so far as we can judge. It seemed at first as if the helium line, principal series, 3888.785, was different on various plates; but the differences observed proved to be due not to the line itself but to lines exceedingly close to it. It is possible that the difference between heavy and light helium is due to the presence of an impurity, which, although occurring in varying amounts, may still give rise to a strong spectrum.

JOHNS HOPKINS UNIVERSITY,
December 1896.

OXYGEN IN THE SUN.

By Lewis E. Jewell.

In the Astrophysical Journal for December is a short paper by C. Runge and F. Paschen, in which they conclude that probably three lines in the solar spectrum at λ 7772.20, 7774.43, and 7775.62 (Higgs' map) coincide in position with three lines of oxygen produced in the vacuum tube under certain conditions. Mr. McClean had examined the lines upon photographic plates and had concluded that the three lines in question were probably produced in the Sun's atmosphere and not in that of the Earth.

I have examined these lines, using the large plane grating spectrometer at the Johns Hopkins University. The grating is five inches wide and has 15,000 lines to the inch. It is one of the finest gratings ever ruled and wonderfully bright in the red; when it was new I observed lines below λ 8600 in the infra-red. Observations were made on December 23, 24, 25, 27, and 31, 1896 and on January 4, 1897.

On December 31 and January 4 the air was warm and very humid, while upon the other days it was dry and cold.

Some attempts were made to see what effect the Sun's rotation produced upon these lines; but the spectrum is exceedingly weak to the eye when the slit of the spectroscope is placed near the edge of the Sun's disk, so that no satisfactory observations of this character have yet been made. Other observations, however, were so decisive in their character that confirmation by this method is not necessary.

At noon of December 24 with the Sun at an altitude of 27°, the lines at λ 7772.20 and 7774.43 (the strongest lines of the supposed oxygen triplet) were weaker than the lines in the 15th pair in the tail of A (due to atmospheric oxygen). Near sunset, when the Sun's altitude was about 4°, the lines in question were stronger than those of the 14th pair of A. The sunlight at

the last observation passed through five times as much atmosphere as during the former observation, and the lines of atmospheric oxygen had correspondingly increased in intensity. As these comparisons show that the suspected lines had increased much more in intensity than those of atmospheric oxygen used for comparison, it was evident that the suspected lines were unquestionably produced in the Earth's atmosphere but could not be due to atmospheric oxygen. Comparisons were also made with the solar line at λ 7699.1; and, while the suspected lines was *very much* weaker than the solar line at noon, near sunset they were stronger.

Observations were made under similar conditions on December 25 and 27, and the previous results confirmed.

On December 31 the air was warm and very moist. With the Sun at an altitude of 27°, the lines were weaker than those of the 14th pair of A and stronger than those of the 15th pair, being nearer the 14th. Observations made during both the morning and afternoon, when the Sun's altitude was about 15°, showed the lines to be slightly stronger than those of the 13th pair of A. (These results were confirmed by observations of Dr. J. S. Ames.) Observations made later in the afternoon showed that the lines were becoming relatively stronger; but the air was getting hazy and the spectrum weak; so that no reliable estimates could be made, though the lines could be seen until the Sun was about 5° from the horizon.

On January 4, an observation was made with the Sun at an altitude of 27° 30′, and the lines in question were stronger than those of the 14th pair of A but weaker than those of the 13th pair. Observations upon known water-vapor lines showed the humidity of the air to be greater than upon December 31. Clouds however prevented any further observations; but those already made prove conclusively that the three lines supposed to be due to oxygen in the Sun are produced by water vapor in the Earth's atmosphere.

JOHNS HOPKINS UNIVERSITY,
January 4, 1897.

ON THE EFFECT OF PRESSURE IN THE SURROUNDING GAS ON THE TEMPERATURE OF THE CRATER OF AN ELECTRIC ARC. CORRECTION OF RESULTS IN FORMER PAPER.[1]

By W. E. WILSON and G. F. FITZGERALD.

IN May 1895 a preliminary paper by one of the authors was read at the Royal Society, in which is described the apparatus used for these experiments, and the results which were then obtained.

The primary object of this research was to determine, if possible, whether the temperature of the crater in the positive carbon varies when the pressure in the surrounding gas is changed.

It has been suggested that the temperature of the crater is that of boiling carbon. The most modern determinations give this temperature of the crater as about 3300°–3500° C.[2]

If this is the true boiling point of carbon, it is then clear that solar physicists must find some other substance than solid carbon particles to form the photospheric clouds in the Sun, as the temperature of this layer is most probably not below 8000° C.,[3] unless, indeed, the pressure in the solar atmosphere is sufficient to raise the boiling point of carbon to about this temperature. It is in order to throw some light on this subject that these experiments were undertaken.

The gas used in our first experiments was nitrogen, and we found that the radiation from the crater fell off in a most remarkable manner whenever the pressure was raised in the box surrounding the arc. This falling off was not due to any very large extent to visible cloud or smoke, and the crater seemed so much reduced in temperature as to glow with only a red heat. This seemed to show that the temperature of the crater depends

[1] Read before the Royal Society.

[2] WILSON and GRAY, *Proc. R. Soc.*, 58; Violle, *Jour. de Phys.*, 3d series, 2,545.

[3] WILSON and GRAY, *Phil. Trans.*, A, 185, 1894.

on how much it is cooled by the surrounding gas, and not on its being the temperature at which the vapor of carbon has the same pressure as the surrounding atmosphere.

It was found that we were limited to pressures not exceeding about 20 atmospheres, as at this pressure we could not withdraw the negative carbon sufficiently to see into the crater without the arc breaking. We were then only able to obtain a current from a battery of accumulators which had an E.M.F. of 110 volts. Since then we obtained a Crompton dynamo which could give 300 volts and 15 amperes, and which was driven by a turbine.

From the great difficulty of obtaining a sufficient quantity of pure nitrogen under pressure, we obtained a 20-foot cylinder of air compressed to 120 atmospheres. With this we tried a series of experiments, and these at first seemed to corroborate our former ones, in which we used nitrogen, but we found that at any rate some of the radiation, and possibly a great deal of it, was cut off by the formation of what appeared to be red fumes of NO_2. We found no absorption from this cause so long as the pressure was nearly atmospheric, but at about 100 pounds pressure this gas was formed with great rapidity, and undoubtedly cut off a great deal of the radiation. We easily confirmed our belief in the presence of this gas by its well-known absorption spectrum.

Lest heat dissociation might cause an apparent increase in the amount of NO_2, we tried heating some of this gas in a flask. We observed that when hot the brown fumes became golden yellow, and the absorption bands nearly disappeared, so that the heating could *not* have been the cause of the apparently enormous production of NO_2 at high pressure.

We next tried whether oxygen blown into the arc would burn up the carbons, but found it did not do so to any serious extent, and so tried the arc in a compressed atmosphere of this gas.

The arc burned very nicely indeed in the oxygen, the carbons keeping a good shape and a very steady crater. The oxy-

gen was, however, so contaminated with nitrogen that at high pressure enormous quantities of NO_2 were again formed, so that we could not proceed further with the radiation experiments. The arc was a bright blue bead, about the size of a pea, and the spectrum was a beautiful banded one.

From these results we concluded that the reduction of radiation and red-hot appearance of the crater in the former experiments in nitrogen were due to its being contaminated with oxygen, and to the large quantities of NO_2 which were formed by the arc when under pressure.

We next tried the arc in hydrogen. The gas was obtained as pure, but contained hydrocarbons as an impurity, possibly from having been compressed into a cylinder which had previously been charged with coal-gas.

The arc in hydrogen at atmospheric pressures was a long, thin flame, that moved as far up the carbons as possible; especially on the negative carbon it walked up a centimeter along the cone. It went so far that it fused the copper ring that held the negative carbon, and we had to replace it by an iron wire lashing. It was very unsteady, and trees of soot and a deposit of hard graphitic carbon formed on this positive carbon as if there were electrolysis of the hydrocarbon, and carbon were electro-negative compared with hydrogen. This growth took place all round the crater, while there was no tendency for anything to grow on the negative carbon.

The arc was only $5–6^{mm}$ wide, and sometimes over 2^{cm} long. There was a green outer flame, with a bright red line not 1^{mm} wide down the middle of it. Where it impinged on the negative carbon there was a bright red flame from the middle of the bright spot on the carbon. The outer greenish part seemed to give much the same spectrum as the green cone in a Bunsen burner, while the red flame and line was undoubtedly glowing hydrogen. As we saw the C and F hydrogen lines very distinctly, the red C line being dazzlingly bright and not nearly so wide as in a coil spark at atmospheric pressure whenever the image of the red part of the arc was thrown on the slit of the

spectroscope, the appearance was quite like that of a solar prominence.

The end of the positive carbon was pitted into a number of craters, as the arc was very unsteady, and when the pressure was raised it was almost impossible to keep an arc going, partly because the arc broke when it was elongated the least bit, and partly because a complete lantern of soot trees grew all round the crater, and seemed to short circuit the arc from time to time.

The arc being very unsteady, no satisfactory reading of the voltage and current was possible. At from 60 to 80 pounds pressure the voltage varied from 60–80, and the amperes kept continually varying from 15–20. At 40 pounds with 20 amperes the volts varied from 50–60. The crater was not well developed, so that the radiation observation, even at low pressures, was not very satisfactory, while at high pressures the arc was too short to see into the crater at all, and the lantern of soot trees hid a considerable length, 3^{mm} or 4^{mm}, of the negative carbon besides. The radiomicrometer gave 440 divisions with a good arc in air, and 380 with the moderately good crater in hydrogen. But this difference is no greater than would often occur with a good and moderately good crater, so that there is not any proof of a difference of temperature due to cooling power of hydrogen. These experiments showed us that it was quite hopeless to get any measures of radiation under pressure with hydrogen.

We finally tried an atmosphere of carbon dioxide. We used a cylinder of liquid CO_2, which was connected to our arc box by a copper tube and stop valve. The arc burned fairly well in this gas, and, except for the difficulty of getting a sufficiently long arc at pressures above 150 pounds, some pretty satisfactory measures of radiation were obtained. We found that whenever the pressure was suddenly reduced there was a fog formed in the box, which cut off the light enormously. Also by looking down the steel tube, which is closed at its end by a lens, we could see powerful convection currents in the gas which scattered a lot of light. At high pressure the refraction due to these currents prevented any sort of an image of the crater being formed

while the pressure was varying. While the pressure was steady a good image could be formed. This tube is nearly 3 feet in length, and only one-half inch in bore, and it would naturally take time for the gas to settle down throughout its length. We propose to have this tube removed, and the aperture in the box closed by a strong piece of plane glass, and to form an image of the carbons by a lens placed at a suitable distance outside. This we expect will remove the difficulty arising from these convection currents.

The result of all these experiments so far is that it would require more evidence than we have been able to get to affirm that either the temperature of the crater of the arc is raised or lowered by pressure. We got some very concordant observations, which showed the temperature to be lowered with pressure, and in which at the time we could see no evidence of absorption by fog; but then, at other times, there was undoubtedly absorption from this cause. We certainly got no evidence that there is any appreciable increase of temperature. When the arc was started in the gas at a low pressure and then the pressure was raised, the radiation at the low pressure was greater than at high pressure; but when the arc was started first in the gas at high pressure, and then the pressure reduced, the radiation was rather higher in the gas at high pressure. From all this we concluded that the greater part of the differences we were observing were due to the absorption of the light in the long tube already mentioned, which increased the longer the arc was kept burning, and was probably greater at high than at low pressures. The best observations were made with variations of pressure from 15 up to 100 pounds per square inch, and there seems very little evidence of much change of radiation with this change of from 1 up to between 6 and 7 atmospheres.

The whole question is surrounded with great difficulty. If the carbon be really in equilibrium with its own vapor at the temperature of the crater and at the pressure of the surrounding atmosphere, some relation must exist between the change in pressure and change in temperature of the crater. If we knew

the latent heat of volatilization of carbon, we should be able to calculate the change of temperature from the well-known thermodynamic formula

$$\frac{\delta T}{T}=\frac{\Delta v}{\lambda}\cdot\delta p.$$

Δv can certainly be approximately determined on the supposition that the absolute temperature of the crater is fifteen times the absolute temperature of the freezing point, *i. e.*, 3800°. We thus get for gaseous carbon $\Delta v = 10^4 qp$ at this temperature. For 1 atmosphere $\delta p = 10^6 qp$, so that

$$\frac{\delta T}{T}=\frac{10^{10}}{\lambda}.$$

Hence, unless the latent heat of carbon be enormously great compared with that of other substances, $\delta T / T$ will be considerable. If λ be as great as the latent heat of vaporization of carbon given by Trouton's law, *i. e.*, about 4000 calories, or 16.8×10^{10} ergs, $\delta T / T$ will be about $\frac{1}{17}$, and δT will be nearly 220°C. for each atmosphere, and a change of pressure of about 18 atmospheres would raise the temperature of the crater to that estimated for the Sun. The corresponding increase of radiation would be very great, for the radiation varies, at least approximately, as the fourth power of the absolute temperature. This would lead one to expect that the radiation would be nearly doubled for each 4 atmospheres added. Such an increase as this certainly does not take place, so that we may conclude that either the temperature of the crater is not that of boiling carbon, or else that the latent heat of volatilization of carbon is very considerably greater than that calculated from Trouton's law. Even though this latent heat were as great as the heat of combustion of C to CO_2, *i. e.*, 7770°, there would be an increase of about 70 per cent. in the radiation for an increased pressure of 6 atmospheres. Such an enormous latent heat is unprecedented, and yet our experiments would almost certainly have shown such an increased radiation as this. So far, therefore, the experiments throw considerable doubt on the probability that it is the boiling point of carbon that determines the temperature of the crater. It might be

questioned whether there is energy enough in the current to do all this work, but upon an extravagant estimate of the amount of carbon volatilized in the crater, it appears that there is more than a hundred times as much energy supplied by the current as would be required for volatilizing the carbon, even though its latent heat were as great as the heat of combustion of C into CO_2.

There is another considerable difficulty in the theory of the temperature of the crater being that of boiling carbon arising from the slowness of evaporation. The crater on mercury is dark, but then it volatilizes with immense rapidity and the supply of energy by the current being more than 100 times that required merely for evaporation, there seems very little reason why even a considerable difference in latent heat should make any sensible difference in the rate of evaporation of mercury and carbon, especially as, at the same temperature, the diffusion of carbon vapor is nearly three times as fast as that of mercury vapor and the temperature immensely higher.

We would, in conclusion, call attention to a cause of opacity in the solar atmosphere that is illustrated by the effect of convection currents in the long tube we were observing at high pressures; these convection currents behaved just like snow, or any other finely divided transparent body immersed in another of different refractive index. Light trying to get through is reflected backwards and forwards in every direction, until most of it gets back by the way it came. The consequence was that even the electric arc light was unable to penetrate the tube at high pressure, when these convection currents were active. The only light that came out of the tube was the feeble light outside, which was returned to us by reflection at the surfaces of these convection currents. In a similar manner we conceive that any part of the solar atmosphere which is at a high pressure, and where convection currents, or currents of different kinds of materials, are active, would reflect back to the Sun any radiations coming from below, and reflect to us only the feeble radiations coming from interplanetary space. In his paper on "The Physical

Constitution of the Sun and Stars" (*Proc. R. Soc.*, No. 105, 1868), Dr. Stoney called attention to an action of this kind that might be due to clouds of transparent material, like clouds of water on the Earth, but in view of the high solar temperature it seems improbable that any body, except perhaps carbon, could exist in any condition other than the gaseous state in the solar atmosphere; so that it seems more probable that Sun-spots are due, at least partly, to reflection by convection streams of gas, rather than by clouds of transparent solid or liquid particles.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. XVII.

By Henry A. Rowland.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3439.735		000 N	3444.217		0000
3439.841		0000	3444.402	Ni?	2
3439.941		0000	3444.467	Ti	4
3440.008	Fe	3	3444.590		0000 N
3440.138		000 N	3444.654		0
3440.235		00 N	3444.774		0000
3440.328		000 N	3444.847		00
3440.505		0 N	3445.030		000 Nd?
3440.635		000 N	3445.260	Fe	5
3440.762 s	Fe	20	3445.477		000 N
3440.875		00 N	3445.597		000 N
3441.021		000 N	3445.741	Fe, Cr	2 N
3441.155 s	Fe	15	3445.905	Fe	2
3441.248		000 N	3445.947		0000
3441.391		0 Nd?	3446.127		0000
3441.588	Cr	1 N	3446.240		1
3441.688	Pd	0000 N	3446.314		000
3441.808		0000 N	3446.406	Ni	15
3441.875		000	3446.536		1 Nd?
3442.035		0000	3446.620		0000 N
3442.118	Mn	6	3446.747		0000 N
3442.188	Ni	1	3446.857		000
3442.284		1	3446.931		00
3442.368		00	3447.089		0
3442.503	Fe	2	3447.154		00 N
3442.696	Ni	0	3447.290		0000 N
3442.813	Fe	3	3447.420	Fe, Co	4
3442.921		0000	3447.569	Cr	0
3443.059	Co	2	3447.674		0000 N
3443.101	Fe	1	3447.774		000
3443.181		00	3447.901	Cr	0
3443.330	Co	0	3448.040		0000 N
3443.435		000 N	3448.144		1
3443.517		1	3448.227		0000
3443.575		0000 N	3448.340		0 Nd?
3443.691		0000	3448.494		000 N
3443.791	Co	5 d?	3448.597		000 N
3443.908		00 N	3448.727		000 N
3444.020 s	Fe	8 N	3448.827		0000 N
3444.127		0 N	3448.926		0

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3449.003		0	3455.736	Cr	0
3449.099		0000	3455.828		0000 N
3449.186		0000	3455.928		0000Nd?
3449.310	Co	5 d?	3456.081		0000
3449.446		0000	3456.148		00
3449.583	Co	6 d?	3456.228		000
3449.766		0000 N	3456.383	Fe	0
3449.833		0000 N	3456.528	Ti	3
3449.996		000 Nd?	3456.634		0000 N
3450.123		000 Nd?	3456.714		0000 N
3450.275		00	3456.801	Ti	00 N
3450.373		0000 N	3456.944		000 N
3450.469	Fe	5	3457.068	Co	1
3450.589		0000 N	3457.230	Fe	2
3450.742		0000 N	3457.281		00
3450.882		0000 N	3457.414		0000 N
3450.995		000 N	3457.538		0000 N
3451.129		0000	3457.648	Fe, Zr	0
3451.255		00	3457.708		0
3451.369		0000	3457.758		000
3451.477		0	3457.908		0000 N
3451.609	Mn	0	3458.028		0
3451.761	Fe	2	3458.144		000
3451.915		0000 N	3458.254		0
3452.057	Fe	3	3458.442	Fe	3
3452.419	Fe	4	3458.601	Ni	8
3452.609	Ti	1	3458.728		0 N
3452.762		000	3458.834		0 Nd?
3452.919		00 N	3459.074	Zr	00
3453.039	Ni	6 d?	3459.194		0000
3453.169	Fe	2	3459.288		000
3453.255		000	3459.414		000
3453.355	La	0000	3459.568	Fe	2
3453.469	Cr	0	3459.714		0000
3453.621	Co	3	3459.761		0000
3453.705		2	3459.881	Fe	1
3453.885		00	3460.052	Fe	3 d?
3453.982		0000 N	3460.174	Mn,-	2
3454.303	Ti	1	3460.294		0000
3454.455		00	3460.460	Mn,-	4 d?
3454.602		0000 N	3460.568	Cr	000
3454.725		000 N	3460.691		0000 N
3454.829		0000 N	3460.741		0000 N
3454.934		0000 N	3460.874	Pd	00
3455.058		0000	3461.021		000 N
3455.121	Mn	000	3461.111		00
3455.204	Mn	000	3461.321	Co, La	0
3455.379 S	Co	5	3461.413		0000 N
3455.494		0000 N	3461.633	Ti	5
3455.601		0000 N	3461.801	Ni	8

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3461.930		0 N	3468.612		0 N
3462.073		00 N	3468.821		1
3462.217		0000 Nd?	3468.986	Fe	2
3462.347		000	3469.114		0
3462.492	Fe	1	3469.155	Fe	2
3462.667		0000 Nd?	3469.532		0
3462.867		00 N	3469.628	Ni	3
3462.950	Co	6	3469.736	Cr	0
3463.153	Zr	0	3469.826		0000 N
3463.323		0000 N	3469.972	Fe	2
3463.444	Fe	1	3470.076		0000
3463.520		0000	3470.156		0000
3463.660		0000 N	3470.276		0000 N
3463.777		0000 Nd?	3470.380		000 N
3463.937		0000 Nd?	3470.536		00
3464.113		2	3470.678		0
3464.167		00	3470.776		0000
3464.275	Fe	1 d?	3470.876		00
3464.608 s		1	3471.000		0000
3464.843		000	3471.136		0000
3464.970		0000	3471.256		000
3465.052	Fe	0	3471.404	Fe, Zr	3
3465.167		0000	3471.499	Fe, Co	3
3465.300		0000	3471.598		0
3465.390	Cr	00	3471.750		000
3465.467		0000 N	3471.856		000
3465.573		0000 N	3471.910		0000
3465.687		1	3472.035		1 N
3465.779		1	3472.190		00 N
3465.900 } s	Co	4	3472.316		0 N
3466.015 }	Fe	6	3472.443		00 N
3466.137		00 N	3472.593		0
3466.187		00 N	3472.680	Ni	{ 5
3466.320		00	3472.730		{ 2
3466.420		0	3472.850		0000 N
3466.507		0000 N	3472.916		000
3466.639	Fe	3	3473.040		000
3466.773		0	3473.146		000
3466.853		0000	3473.190		0000
3467.033	Fe	2	3473.363		0000
3467.153		000 N	3473.435	Fe	2
3467.270		000 N	3473.637	Fe	1
3467.407	Ti	00	3473.756		0
3467.517		0000 N	3473.823	Fe	1
3467.644	Ni	3	3473.950		0000
3467.845	Ni, Cr	2	3474.106	Co	2
3468.007		000	3474.197	Mn	2
3468.210		00	3474.287	Mn	2
3468.347		0000 N	3474.410		0000
3468.486		0000 N	3474.523		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3474.576	Fe	2	3480.549		000
3474.669		00	3480.669	Ti	1
3474.800		000	3480.785		0000 N
3474.904		1	3480.875		0000 N
3475.023		00	3481.024	Ti	2
3475.143		0000 N	3481.195		00 N
3475.270		2	3481.302	Pd, Ti-Zr	2
3475.406		0	3481.439	Cr	0
3475.456		00	3481.589		0000
3475.594 s	Fe	10	3481.695	Fe, Cr	2
3475.656		0 N	3481.802		0000
3475.802	Fe	2	3481.889		000
3475.894		1	3481.952	Fe	00
3476.010	Fe	2	3482.075		000
3476.163		000 N	3482.195		000
3476.330		0000 N	3482.325	Fe	1
3476.479	Co, Fe	3	3482.589		000
3476.590		0000	3482.712		000 Nd?
3476.756		0	3482.855	Zr	00
3476.849 s	Fe	8	3483.047	Mn-	5 d?
3477.002	Fe	1	3483.155	Fe	4
3477.125	Fe, Ti	3 d?	3483.295		0000
3477.323	Ti	5	3483.553	Co	3
3477.500		000	3483.667	Fe, Zr	0
3477.636		00	3483.769		000
3477.770		0	3483.923	Ni	6 d?
3477.856		0000	3484.023		1
3478.002 s	Fe, Ni	4	3484.172		0000 N
3478.123		000	3484.295		3
3478.256		0000 N	3484.352		00
3478.316		0000 N	3484.482		000 Nd?
3478.438	Ni, Zr	0	3484.692		0000Nd?
3478.504	Fe	0	3484.809		0000 N
3478.689	Co, Zr	0	3484.922		00
3478.772	Fe	1	3484.995	Fe	1
3478.876		0000	3485.121	Fe	2
3478.923	Co	0	3485.249		1
3479.053		000	3485.369		0000 N
3479.163	Zr	0	3485.493	Fe Co	6
3479.273		0000	3485.645		0000 N
3479.401	Ni	1	3485.719		0000 N
3479.531	Zr	2	3485.845		00 N
3479.703		0000 N	3486.041 s	Ni	5
3479.829	Fe	1	3486.179		0000
3479.969		0	3486.282		0000
3480.061		1	3486.362		000
3480.171		00	3486.475		000
3480.315	Ni	1	3486.522		0000
3480.442		0000	3486.691	Fe	2
3480.476	Fe, Zr	2	3486.782		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3486.889		0000	3493.313		0 N
3486.962		0000	3493.430	Ti, Fe	1
3487.095	Mn	00 N	3493.618		2
3487.145		0000	3493.721		00
3487.289		0000	3493.834	Fe	1
3487.415		0000	3494.004		00
3487.542		000	3494.154		0000 N
3487.743		2	3494.308	Fe	2
3487.857	Co, Ca	0	3494.401		0000
3487.959		000	3494.498		0000
3488.131		2	3494.551		0000
3488.289		0c00 Nd?	3494.654		0
3488.437	Ni, Mn	0	3494.815	Fe	2
3488.589		000	3494.871		000
3488.702		0000 N	3494.994		0000 N
3488.817	Mn	4	3495.108	Cr	00
3488.965		1	3495.178		0000 N
3489.142		00 Nd?	3495.384		0
3489.302		00 N	3495.423	Fe	3
3489.392		0000 N	3495.522		2
3489.546	Co	5	3495.658		000
3489.813	Fe	3	3495.802	Co	3
3489.889	Ti, Pd	2	3495.853	Ti	2
3490.048		0000	3495.974	Mn	2
3490.104		0000	3496.024	Fe	2
3490.191		0000	3496.101		0000
3490.301		0	3496.224	Co	0
3490.341		0000	3496.348	Zr	2
3490.441		0000	3496.491	Ni	0
3490.534		00	3496.614		0000 N
3490.628		0	3496.721		0
3490.733 s	Fe	10 N	3496.820	Co	3
3490.896	Co	0	3496.952	Co, Mn	3
3491.008		000 Nd?	3497.148		1
3491.195	Ti	5	3497.241 } s	Fe	3
3491.354		000	3497.301 } s		2
3491.462 s	Co,-	4	3497.421		0000 N
3491.661		0000 N	3497.534		0
3491.894		000	3497.668	Mn	3
3492.021		0000 N	3497.874		0 N
3492.112	Co	00	3497.982 s	Fe	8
3492.174		0000	3498.116		0
3492.284		0000	3498.322		1 N
3492.368		000 N	3498.451		0000 N
3492.508		00 N	3498.534		0000 N
3492.678		000 N	3498.668		00
3492.858		000 N	3498.888		1
3492.954		00 N	3499.084		00
3493.114	Ni	10 N	3499.248	Ti	0
3493.228		000 N	3499.408		00

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3499.492		0	3505.371		0000
3499.608		0000 N	3505.433		0
3499.711		0	3505.525		0000
3499.848		0000 Nd?	3505.628	Zr	0
3499.974		0000	3505.810	Zr-V	1
3500.013		0	3505.928		0000
3500.131		000	3506.038		0
3500.296		0	3506.189		000
3500.474	Ti	3	3506.380	Fe	1
3500.577		0000	3506.467	Co	5
3500.706 s	Fe	2	3506.645	Fe	3
3500.830		0000 N	3506.733	Ti	1
3500.996 s	Ni	6 d?	3506.793		0000
3501.094		0000	3506.891		0000
3501.210		0000	3506.980		0
3501.296		0000	3507.077		0000
3501.394		0000	3507.284		2
3501.472		000	3507.350		0
3501.605		000 N	3507.447		0000
3501.710		0000 N	3507.543	Fe	1
3501.841		0	3507.687		0000 N
3501.868		0	3507.837	Ni	3
3501.970		000 N	3507.957		000
3502.104		000 N	3508.090		00
3502.165		0000	3508.234		000
3502.394		{ 3	3508.350		1
3502.466	Co	{ 3	3508.487		0000 N
3502.608		00	3508.626	Fe	3
3502.737	Ni	2	3508.670	Fe	2
3502.775	Co	2	3508.847		0000 N
3502.899		0000	3509.037		00
3503.001		00	3509.157		0000
3503.112		0000	3509.264	Fe	2
3503.256		000 N	3509.470		0000
3503.442		000 N	3509.570		0000
3503.612		1	3509.690		0000
3503.699		0000	3509.870		1
3503.866	Co	00 Nt?	3509.992	Co, Fe	4
3504.048		00	3510.209		000
3504.192		0000	3510.331		1
3504.332		0000	3510.466	Ni	8
3504.399		0000	3510.596	Co, Fe	2
3504.581	Fe, V	2	3510.693		00
3504.733		0000	3510.824		1
3504.823		1	3510.985 s	Ti	5
3504.885	Co	0000	3511.209		0000 Nd?
3505.015	Fe	3	3511.356		0000
3505.056	Ti	2	3511.453		0000
3505.202	Fe	3	3511.583		0000
3505.288	Co	0000	3511.676		0000

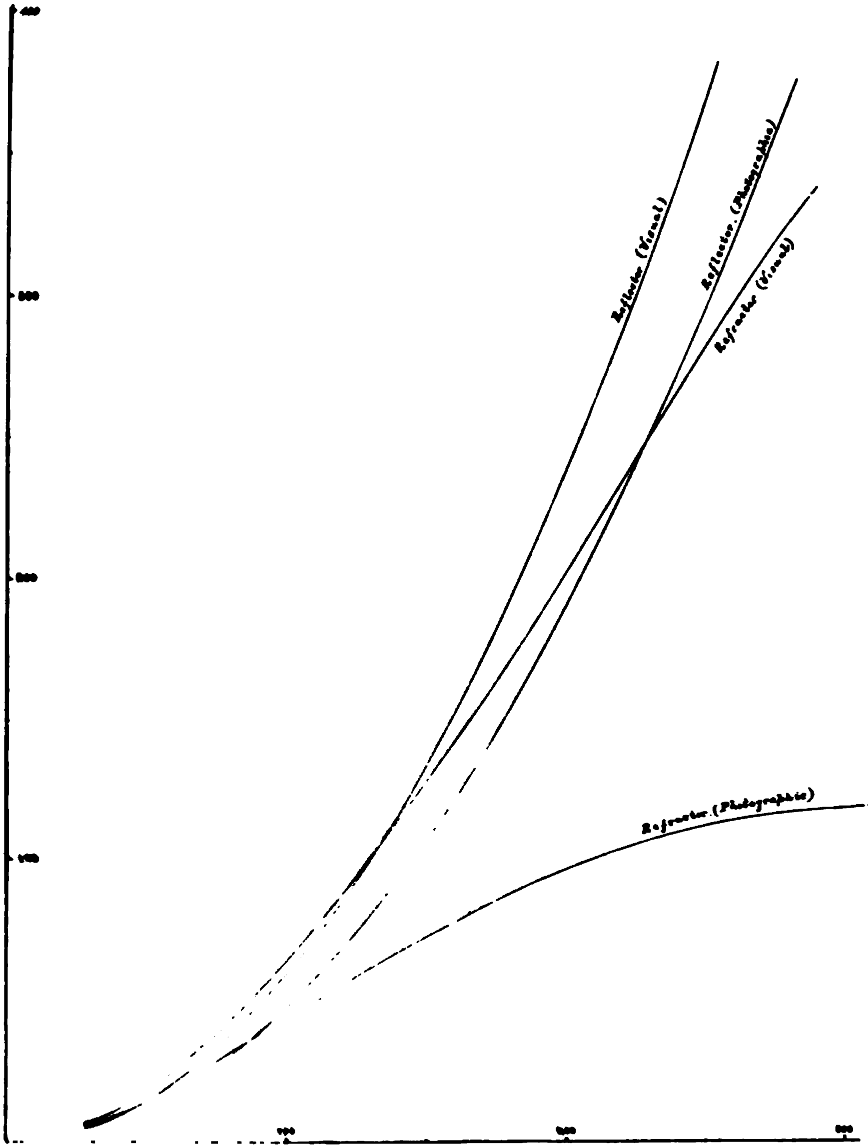
Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3511.763	Mn	0	3518.790	Ni	4
3511.883	Fe	1	3518.825	Fe	3
3511.978	Mn	2	3518.933		0000
3512.066		00	3519.014	Ti, Fe	3
3512.228	Fe	1	3519.239	Tl?	0000Nd?
3512.369	Fe	2	3519.531		0000
3512.520		000	3519.645		0000
3512.639		0000	3519.758		0000
3512.785	Co	6	3519.904	Ni	7
3512.869		00	3520.021		0000
3512.950		00	3520.168		2
3513.100	Fe	1	3520.228	Co	3
3513.200	Fe	2	3520.397	Ti	2
3513.422		0000 N	3520.531		0000
3513.623	Co	5	3520.675	Fe	000
3513.744		000	3520.751		0000
3513.868		00	3520.871		0000
3513.965 s	Fe	7	3520.991	Fe, Zr	2
3514.082		4	3521.118		0000
3514.138	Ni	3	3521.205		0
3514.382		0000 N	3521.318		00
3514.608		0	3521.410 s	Fe	8
3514.775	Fe	2	3521.686		3
3515.206	Ni	12	3521.748	Co	4
3515.549		0	3521.888		000
3515.675		00	3521.984	Fe	2
3515.787		0000	3522.184		0000
3515.947		0000 N	3522.284		0000
3516.021		0000 N	3522.412	Fe	4
3516.156		000	3522.589		00
3516.261		0000	3522.677		0000
3516.359	Ni	2	3522.757		0000
3516.441		0000	3522.877		000
3516.554	Fe, Co	2	3522.974		000
3516.701	Fe	2	3523.048	Fe, Co,-	2
3516.854		0000	3523.212	Ni	1
3516.959		0	3523.324		0
3517.093	Pd	00	3523.452	Fe	2
3517.173		0000	3523.584	Co	4
3517.310		0000 N	3523.700		000
3517.446	V	3	3523.850	Co	0
3517.523		0000	3523.924		0000
3517.653		000 N	3524.130		000
3517.860		0000 N	3524.221	Fe	3
3517.960		0000 N	3524.385	Fe	3
3518.103		0000	3524.499		0
3518.200		0000	3524.677	Ni	20
3518.360		0000	3524.883		1
3518.488 s	Co	5	3525.063		000 N
3518.636		0000	3525.271		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3525.416		0000	3532.143	Mn	4
3525.529		0000	3532.262	Mn	3
3525.656		0000	3532.469		000
3525.759		2	3532.601		0000
3525.986	Fe	4	3532.721	Fe,-	4
3526.103		00	3532.777		00
3526.183	Fe	6	3533.041		0000
3526.311		3	3533.156	Fe	6
3526.398	Fe	2	3533.345	Fe	6
3526.526	Fe	2	3533.506	Co	5
3526.625		2	3533.680		0000
3526.686		0	3533.836	V	000
3526.821	Fe	4	3534.000	Ti	1
3526.988	Co	6	3534.206		0000
3527.115		0	3534.400		000
3527.252		00	3534.672	Fe	2
3527.368		0000	3534.733		0000
3527.458		000	3534.830		0000
3527.588		0000	3534.920	Co	000
3527.672		000	3535.060	Fe	3
3527.750		1	3535.090		00
3527.936	Fe	5	3535.180		0000N
3528.041		0	3535.300		0000 N
3528.133	Ni	4	3535.446	C	000
3528.382		0	3535.554	Ti	4
3528.465		00	3535.660		0000
3528.552		0000	3535.766	C	000
3528.715		0000 N	3535.868		3
3528.928		0000	3535.989		0000
3529.035	Ni	1	3536.165		00
3529.181	Co	3	3536.259		0000
3529.328		00	3536.405		0000 N
3529.495		00	3536.709	Fe	7
3529.662	Fe	2	3536.832		0000
3529.768	Ni	1	3536.934		00
3529.872		00	3537.025		0000
3529.964	Fe-Co	6	3537.105		00 N
3530.136		0000	3537.265		0000Nd?
3530.264		0000	3537.385	Ni, C	1
3530.374		0000	3537.439		0000
3530.533	Fe-	3	3537.638	Fe	2
3530.734	Ni, Ti	1	3537.772	Co	0
3530.919		3	3537.879	Fe	3
3531.107		00	3538.045	Fe	4
3531.247		0000 N	3538.219		0000 N
3531.424		0000 N	3538.399		1
3531.582	Fe	2	3538.452	Fe	1
3531.761		0000	3538.555		0000
3531.851		1	3538.643		1
3531.982	Mn	3	3538.701	Fe	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3538.832		0000	3544.888		0000
3538.937	Fe	1	3545.001		0000
3539.081	C	00	3545.054	C	000
3539.218	C	00	3545.128	C	000
3539.391		0000	3545.194		0000
3539.513		0000	3545.336 s	-,V	4
3539.588		000	3545.481		0000 N
3539.684		0000	3545.654	C	0
3539.771		0000	3545.786	Fe, C	5
3539.892		00	3545.971	Fe, C	3
3540.038	C	00 N	3546.048		0000
3540.098		0000	3546.161		0000
3540.268 s	Fe	5	3546.348		1
3540.464	C	000	3546.488		0000
3540.538		000	3546.568		0000
3540.644		0000 N	3546.684		00
3540.857	Fe	3	3546.851	Co	00
3540.950	Fe	2	3546.921		000
3541.108		00 N	3546.974		000
3541.237	Fe	7	3547.121		0000
3541.384		00 N	3547.168	Ti	0
3541.474		000	3547.320		3
3541.687	C	000	3547.362	Fe	3
3541.790		0000	3547.511		0000Nd?
3542.017	C	000	3547.640		0000
3542.129	Ni	0	3547.780		000 N
3542.232	Fe	6	3547.941	Mn	5
3542.397	Fe	3	3548.087		00
3542.473		0000	3548.175	Mn, Fe	3
3542.583		0000	3548.332	Mn, Ni	5
3542.633		0000	3548.447		0000
3542.713	Ti	00	3548.593	Co	00
3542.775	Zr	00	3548.687		000
3542.910		0000 N	3548.793		0000
3543.090		0000	3548.880		0000
3543.143		0000	3549.047		0000 N
3543.243		0000	3549.151 s	Y ?	2
3543.310		0000	3549.260		0000
3543.407	Co	2	3549.384		1
3543.531	Fe	2	3549.513	C	0
3543.637		0000	3549.667	C	00
3543.824	Fe	3	3549.773		0000
3543.937		0000	3549.907		0000Nd?
3544.075	C	0000	3550.014 s	Fe	3
3544.155	C	000	3550.247		0000
3544.229		0000	3550.363	C	1 N
3544.371		1	3550.510		000
3544.489		0000	3550.627	C	0000
3544.662		000	3550.740	Co	4
3544.776	Fe	3	3550.939	C	000 Nd?

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3551.092	C	0000 N	3557.036		3
3551.253		1	3557.204		0000
3551.376	C	000	3557.304		000
3551.542		000	3557.370		000
3551.674	Ni	4	3557.495		00
3551.800		1	3557.604		0000
3551.912		0000	3557.817		0000
3552.012		0000	3557.907		0000
3552.098	Zr	1	3558.020		0000 N
3552.253	Fe	2	3558.140		0000
3552.449		0000 N	3558.214		1
3552.574		0	3558.350		000
3552.699		0000	3558.477		00 N
3552.866	Co	1	3558.570		0 N
3552.986	Fe	5	3558.672 s	Fe	8
3553.086		000	3558.774		0 N
3553.132	Co	1	3558.923	Co	1
3553.236		000	3559.017		0000
3553.304	Pd	00	3559.124		0000
3553.416		0000	3559.219	Fe	1
3553.491		0000	3559.347		00
3553.624	Ni	3	3559.414		0000
3553.735		0000	3559.604		1
3553.887	Fe	5	3559.656	Fe	3
3554.011		000	3559.750		0000
3554.115		0000	3559.840		0000
3554.263	Fe	5	3559.954		000
3554.418		000	3560.063	Ni	0
3554.438		0000	3560.216		00
3554.593		2	3560.303		000
3554.651	Fe	3	3560.436		000 N
3554.789		1	3560.556		000
3554.938		0 N	3560.649		0000
3555.079	Fe	9	3560.729		1
3555.185		0 N	3560.843	Fe	2
3555.318		000 N	3560.942		0000
3555.425		0000	3561.037	Co	4
3555.498		0000	3561.203		0000
3555.598		2	3561.276		0000
3555.758		0000	3561.419		0000
3555.865		0000	3561.516		0000
3555.945		0000	3561.609		0000
3556.088		000 Nd?	3561.718	Ti	1
3556.291		000	3561.796		0000
3556.405		0000	3561.898	Ni	3
3556.515		0000	3562.043	Fe, Ti	1
3556.631		0000	3562.161		0000
3556.738	Zr	2	3562.236	Co	0 N
3556.830	Fe	2	3562.331		0000
3556.944	Fe	4	3562.410		1

PLATE III.



LIGHT GRASPING POWER OF OBJECTIVES AND SPECULA.

ON THE COMPARATIVE VALUE OF REFRACTING AND REFLECTING TELESCOPES FOR ASTROPHYSICAL INVESTIGATIONS.

By George E. Hale.

Every astrophysicist whose investigations include the spectroscopic study of both the Sun and the stars, must have frequent occasion to contrast the instruments available for use in these two fields of research. In the case of the Sun, the brightness of its light permits the employment of finely ruled gratings of very high resolving power, by means of which it is possible to detect a motion of fifty meters per second in the line of sight. For the production of stellar spectra, on the contrary, the most powerful spectrographs used with the largest telescopes contain no more than three large prisms. With the modest resolving power of such an optical train surprisingly concordant measures of stellar motions have been made by the aid of photography, and investigations of this character can be advantageously prosecuted for many years to come. But those who wish to materially reduce the probable error of wave-length determinations of lines in stellar spectra, either for the purpose of increasing the accuracy of line of sight measurements or to render possible such detailed studies of certain lines as are now made in the solar spectrum, must be content to wait for the construction of telescopes much larger than the great instruments of the present day. It thus becomes a matter of importance to the astrophysicist to consider just what advances in telescope construction are most likely to assist him in his work. Naturally the first question that arises is this: Which form of telescope is the better adapted to stellar spectroscopic and other astrophysical investigations—the refractor or the reflector? It is the purpose of the present paper to point out some of the more important advantages for many classes of astrophysical work which the reflecting telescope seems to possess.

For the sake of preventing possible misapprehension, I wish to point out that the observations for which the reflector seems to be best suited should be sharply distinguished from those for which the refractor has been shown by experience to be the better instrument. In direct visual observations requiring perfect definition the refractor seems to give much better results than the reflector. This may be due to a variety of reasons, of which the most potent seems to be the peculiar sensitiveness of a speculum to variations of temperature and flexure. It is not unlikely that the difficulties due to flexure can be done away with by adopting some such form of support for the speculum as that devised by Mr. G. W. Ritchey, optician of the Yerkes Observatory, which is described on another page.[1] The deformation of the mirror resulting from temperature changes cannot be so easily overcome, but its effect upon the image can be lessened by selecting glass as homogeneous as possible for the speculum, so that the distortion may be of a uniform character. But whether the reflector can be ultimately made to compete with the refractor in direct visual observations it is not my object to discuss at the present time. The work for which the reflector seems to be best adapted includes stellar, planetary, and nebular spectroscopy, photometric, and other radiometric studies of the Moon and planets, and photography of stars and nebulæ; it is to the needs of such observations that special consideration is given in this paper.

For such investigations it may said that the perfection of definition required, for example, in double star observations, is to a large extent superfluous.[2] It cannot be doubted that the reflector, even in its present form, defines quite well enough for all work of this character. In stellar spectroscopy, for instance, the unsteadiness of the stellar image on the slit, due to atmospheric disturbances, is ordinarily such as to completely mask any outstanding spherical aberration. Moreover, the sharpness

[1] See p. 143.

[2] See in this connection Professor Wadsworth's remarks in this JOURNAL, May 1896, p. 347.

of the spectral lines depends only upon the width of the slit, when this is not greater than the effective diameter of the "tremor disk." In the other classes of astrophysical work, almost without exception, to which reference is here made, great perfection of definition is equally unnecessary. Thus the most important objection that can be urged against the reflector has little weight in the present connection.

The relative advantages of refractors and reflectors have been so admirably summed up by Sir Howard Grubb in his memoir "On Great Telescopes of the Future,"[1] that I could hardly do better than to repeat his words. As, however, great improvements have been effected in the manufacture of glass for both lenses and specula since 1877, when this discussion was published, and as I wish to give special attention to the astrophysical side of the question, I shall deviate somewhat from Sir Howard's manner of treatment, at the same time acknowledging my obligations to his important paper.

The principal advantages of a reflector, as compared with a refractor, may be outlined as follows:

1. *Perfect freedom from chromatic aberration.*—That this is a matter of the first importance in astrophysical work can be best appreciated by those who have done spectroscopic work with large refractors. In the Lick telescope the focus for the line $H\delta$ is $81^{mm}.5$ beyond that for D_2. In the Yerkes telescope the corresponding difference is even greater, so that it has been necessary to give the collimator of the stellar spectrograph a range of motion of 150^{mm}. This dependence of focus upon wave-length seriously hampers all classes of spectroscopic work. In investigating the spectrum of a star, the Sun's chromosphere, or any other celestial object, the slit of the spectrograph must be accurately set in the focal plane of the line whose position or intensity is to be determined. Should this line happen to lie on a steep part of the color curve, the rapidly broadening spectrum on either side of it will fail to show faint lines, and incorrectly represent the intensities of brighter ones. For the purpose of

[1] *Trans. R. Soc. Dublin*, New Series, Vol. I, Memoir No. 1.

making comparisons of the relative intensities of various lines in the same spectrum, it is therefore evident that a large refractor can be used, if at all, only with great difficulty. In observing the forms of the solar chromosphere and prominences in various lines it is essential to success that the slit be placed with great exactness in the focal plane of the line in use. It is a very troublesome matter with large spectroscopes to effect this adjustment whenever it is desired to pass rapidly from one line to another. Moreover, in the case of a refractor, the magnification also depends upon the wave-length, so that photographs of prominences or of the Sun's surface taken in different lines with the spectroheliograph cannot be accurately compared without reduction to the same scale. For work with the bolometer, radiomicrometer or thermopile the single focal plane of the reflector is almost indispensable. In determinations of the colors of stars, planets, Sun-spots and similar objects made with a refractor, uncertainty often enters, because of the chromatic aberration. In photometric observations of objects having different spectra, unless the spectra themselves are compared wave-length for wave-length, the reflector will yield more trustworthy results than the refractor. A further matter of great importance is the fact that the whole field of celestial photography lies open to a reflector, which can also be used, without change of any kind, for visual observations. With the ordinary form of refractor either a separate objective must be used for each class of work, or the visual object-glass must be provided with a third correcting lens, or made with the front lens reversible to adapt it for photography. In a word, it would be hard to name a branch of astrophysical work in which the chromatic aberration of the refractor is not a serious drawback.

The interesting and valuable experiments instituted at Jena by the firm of Schott & Co. have resulted in the production of varieties of flint and crown glass with which objectives having little or no chromatic aberration have been successfully made. Unfortunately, however, the glass was found to deteriorate in a short time, a thin opaque film forming on the surface. Recently

Messrs. T. Cooke & Sons have brought out an objective composed of three lenses, which is said to be practically free from chromatic aberration, so far as the visible spectrum is concerned. I do not know that any objectives of large aperture have as yet been constructed on this plan, which of course involves increased cost of manufacture and the added loss of light by absorption and reflection in the third lens. A correcting lens placed over a visual objective to adapt it for photographic purposes is objectionable on account of the change of focus produced, the loss due to additional absorption and reflection, the inconvenience of attaching and detaching a heavy lens and cell and rebalancing the telescope, and the cost. For spectroscopic purposes a small lens placed near the focus would probably be much more satisfactory, as in this case most of the objections urged against a large lens attached to the objective are less serious. However, the field of the corrected objective would be very small, and the telescope would still not be adapted for work in the ultra-violet and infra-red. The new objective of Professor Hastings, which includes a third lens not far from the focus, shows little or no trace of secondary spectrum to the eye. But no combination of lenses yet devised can compare with a paraboloidal mirror in the capacity to unite in a single focal plane all wave-lengths from the extreme infra-red to the ultimate limit of the ultra-violet. Whatever may be the defects of the reflecting telescope, this property, so important in the estimation of the astrophysicist, must certainly be credited to it.

2. *Relatively small absorption for large apertures.*—In an object-glass composed of two lenses light is lost by reflection at four surfaces. The nature and amount of the absorption depend upon the quality of the glass used, but in all cases the most marked effect is in the ultra-violet. As a consequence it is impossible, even with a photographic objective corrected especially for this region, to photograph any considerable part of the ultra-violet spectrum of a star. The reflector, on the contrary, as Dr. Huggins' results so well attest,[1] serves admirably in photo-

[1] His spectrum of Vega reaches λ 2970.

graphing the shortest wave-lengths that penetrate our atmosphere. At the other end of the spectrum glass becomes less and less transparent for the longer waves, and beyond 2^{μ} is practically opaque. Here a reflector exercises almost no absorption and is consequently indispensable for all thermal investigations in the extreme infra-red.

With the aid of the important photometric determinations of the absorption of various kinds of optical glass recently made at Potsdam,[1] we may compare the light-grasping power of specula with that of the best modern objectives. Thanks to the firm of Schott & Co., of Jena, it was possible to select the flint and crown glass for the great Potsdam refractor from a number of samples having different coefficients of absorption. The absorption was determined for various wave-lengths between λ 6770 and λ 3900, and the samples giving the smallest absorption were chosen for the new objective of 80^{cm} aperture. With the data obtained for these chosen specimens of crown and flint glass a table was prepared, giving the absorption for various thicknesses from 4^{cm} to 40^{cm}. To extend this table so that it shall include the absorptive properties of reflecting telescopes, it remains for us to determine the light-grasping power of silvered specula.

In his memoir on "Energy and Vision"[2] Professor Langley gives the following table of the coefficients of reflection from two surfaces of silver. The wave-lengths are expressed in microns.

Wave-lengths . . .	.35	.38	.40	.45	.50	.55	.60	.65	.70	.75
Reflection, two surfaces .	.37	.54	.63	.73	.79	.82	.845	.86	.875	.885

The table is stated to be "for the selective absorption of silver referred to such a lamina as is spread by the Martin process

[1] H. C. Vogel: "Die Lichtabsorption als maassgebender Factor bei der Wahl der Dimension des Objectivs für den grossen Refractor des Potsdamer Observatoriums." *Sitzber. d. K. Akad. d. W. Berlin*, 19 November, 1896, pp. 1219–1231. For a translation of this article see p. 75.

[2] *Mem. Nat. Acad. Sci.*, 5, 10.

on the front surface of the glass in its ordinary application. It is prepared from unpublished observations made by the writer with the bolometer." Unfortunately there seems to be no statement regarding the freshness of the silvered surfaces, and we are left in doubt as to the length of time they had been in use before the determinations were made. In his article on the "Telescope" in the *Encyclopædia Britannica* Dr. Gill remarks that too great reliance must not be placed on measurements of the reflective power of small, freshly prepared silvered surfaces, and adds that he "has found from experience and careful comparison that a silvered mirror of twelve inches aperture mounted as a Newtonian telescope (with a silvered plane for the small mirror), when the surfaces are in fair average condition, is equal in light-grasp to a first-rate refractor of ten inches aperture, or area for area as 2:3." From Professor Vogel's table (given below) we find that over 77 per cent. of the visual rays would be transmitted by a 10-inch objective of Jena glass. Disregarding the unknown difference in the absorptive coefficients of Professor Vogel's and Dr. Gill's objectives, this would indicate that after the loss suffered in two reflections and that due to the interposition of the small mirror in the path of the rays, Dr. Gill's Newtonian reflector brought to the focal plane about 53 per cent. of the visual[1] rays received by the large mirror. For the photographic rays referred to by Vogel (λ 3900 to λ 4550), Langley's results show that this coefficient would be reduced to about 48 per cent., on the assumption that the ratio of the coefficients of reflection for different wave-lengths is the same for bright as for slightly tarnished silvered surfaces. It is evident that on account of a lack of necessary data some degree of uncertainty must attend these figures. It cannot be said just how much light was cut off by the small plane mirror in Dr. Gill's reflector, as its size is not mentioned. It is safe to assume, however, that its shorter diameter was rather less than one-fifth that of the large mirror, and this ratio may be taken as a constant for all apertures. The loss of light due to the small mirror and its

[1] Taken by Vogel as lying between λ 6770 and λ 4550.

support may therefore be considered about 4 per cent. of the whole.

Since Dr. Gill's paper was written the process of silvering glass surfaces has been greatly improved by Brashear and others. In view of this fact, and also in consideration of the marked difference between his result and those of Langley (the latter having been obtained by methods which may probably be regarded as much more precise than the estimate made by Gill), we shall hardly be likely to overestimate the capacity of the instrument if we consider that 60 per cent. of the visual and 48 per cent. of the photographic rays are brought to the focal plane of a Newtonian reflector. If, as is sometimes the case, an optician is employed to keep the silvered surfaces in a highly polished condition, these coefficients may be increased to maximum values of about 78 per cent. for the visual and 61 per cent. for the photographic rays. The smaller coefficients will, however, be adopted for the purposes of the present comparison.

The following table contains the results on the transmission of light through objectives given by Professor Vogel in the paper already mentioned, together with certain additional data concerning Newtonian reflectors. It is probable that the corresponding values for Cassegrainian reflectors would differ from these in no very great degree, though Sir Howard Grubb remarks that less light is lost in this latter form of instrument.[1] In the first column is given the aperture in centimeters, which is taken as seven times the thickness of the objective, in accordance with Professor Vogel's suggestion.[2] The next five columns are reproduced without change from Professor Vogel's table. The ninth and tenth columns give the percentages of light received at the focal plane of a reflecting telescope after the loss experienced in two reflections, and that caused by the small mirror and its supports. The numbers in the seventh, eighth, eleventh, and twelfth columns are proportional to the amount of light concentrated in a stellar image by refractors and reflec-

[1] *Trans. R. Soc. Dublin*, New Series, Vol. I, Memoir No. 1, p. 2.

[2] See p. 89.

Aperture in cm	Thickness in cm	Objective						Silvered glass speculum			
		Intensity of transmitted light when incident light is unity				Light-grasping power		Intensity of reflected light when incident light is unity (Newtonian telescope)		Light-grasping power	
		With respect to absorption alone		With respect to absorption and reflection							
		Visual rays	Rays most active chemically	Visual rays	Rays most active chemically	Visual rays	Rays most active chemically	Visual rays	Rays most active chemically	Visual rays	Rays most active chemically
28	4	0.93	0.84	0.77	0.69	6.04	5.41	0.60	0.48	4.70	3.76
42	6	0.90	0.77	0.75	0.63	13.23	11.11	0.60	0.48	10.58	8.46
56	8	0.87	0.71	0.72	0.58	22.58	18.19	0.60	0.48	18.82	15.05
70	10	0.84	0.65	0.70	0.53	34.30	25.97	0.00	0.48	29.40	23.52
84	12	0.82	0.60	0.67	0.49	47.27	34.57	0.60	0.48	42.34	33.89
98	14	0.79	0.55	0.65	0.45	62.43	43.22	0.60	0.48	57.62	46.10
112	16	0.76	0.50	0 63	0.41	79.03	51.43	0.60	0.48	75.26	60.21
126	18	0.74	0.46	0.61	0.38	96.84	60.33	0 60	0.48	95.26	76.20
140	20	0.71	0.43	0.59	0.35	115.64	68.60	0.60	0.48	117.60	94.08
154	22	0.69	0.39	0.57	0.32	135.18	75.89	0.60	0.48	142.30	113.84
168	24	0.67	0.36	0.55	0.29	155.23	81.85	0.60	0.48	169.35	135.48
182	26	0.65	0.33	0.53	0.27	175.56	89.43	0.60	0.48	198.75	159.00
196	28	0.62	0.30	0.52	0.25	199.76	96.04	0.60	0.48	230.50	184.40
210	30	0.60	0.28	0.50	0.23	220.50	101.43	0.60	0.48	264.60	211.68
224	32	0.58	0.25	0.48	0.21	240.84	105.37	0.60	0.48	301.05	240.84
238	34	0.56	0.23	0.47	0.19	266.23	107.62	0.60	0.48	339.86	271.89
252	36	0.55	0.21	0.45	0.18	285.77	114.31	0.60	0.48	381.02	304.82
266	38	0.53	0.20	0.44	0.16	311.32	113.21	0.60	0.48	424.53	339.63
280	40	0.51	0.18	0.42	0.15	329.29	117.60	0.60	0.48	470 40	376.32

tors, calculated for both the visual and the photographic rays, allowance having been made for all losses in both types of telescope. They are obtained by multiplying the square of the aperture by the percentages given in the preceding columns.

In Plate III are reproduced curves platted from the light-grasping powers given in the table. Ordinates represent light-grasping power, and abscissæ are apertures. It is evident from inspection of the curves that for apertures not exceeding 87^{cm} refractors surpass (Newtonian) reflectors in light-grasp for both visual and photographic rays. As soon as this aperture has been passed the reflector becomes the more efficient collector of the blue and violet rays, while it still gives images that are less brilliant visually. For apertures over 134^{cm} the reflector gives brighter images than the refractor in both the visual and photographic regions. It will be noticed that this aperture is much greater than the corresponding value (about 90^{cm}) deduced some years ago by Robinson in a comparison of the light-grasping power of objectives and speculum metal mirrors. I have adopted small values of the coefficients of reflection, in order to avoid the danger of exaggerating the light-grasping power of specula. The rapid relative gain of the reflector beyond this point can be best appreciated by a glance at the curve.

It is evident that if the silvered surface be kept in excellent condition the superiority of the reflector will be much greater.[1] If the comparison were extended to the infra-red or ultra-violet the refractor would be shown to be of relatively small importance for work with these rays. The percentage of light reflected by a silvered mirror increases with the wave-length. At 1^{μ} it is 96.5 (one reflection), at 2^{μ}, 97.3, and at 4^{μ} practically all the incident light is reflected. For wave-lengths of 6^{μ} and 8^{μ} the percentage of reflection has been found to be as great for old

[1] It is by no means impossible that large specula may ultimately be coated with a highly reflective film of platinum, as small surfaces are now so successfully treated in the laboratory. The experiments of M. Izarn in covering a silvered surface with an extremely thin film of bichromatized gelatine, to protect it from the air, also seem promising. (*C. R.* **118**, 1314.)

and yellow silvered surfaces as for new ones with perfect polish.[1]

3. *Possible large angular aperture.*—In the case of an objective composed of two lenses it is not common to see a ratio of aperture to focal length greater than $\frac{1}{14}$, and it is practically impossible to make a good objective of this sort with a ratio greater than $\frac{1}{8}$. Specula, on the contrary, may be made with a ratio as great as $\frac{1}{4}$. Of course such specula define well only in the center of the field, but this is quite sufficient for the requirements of stellar spectroscopy and other similar work. Large angular aperture is frequently of great value in stellar and nebular photography, in stellar spectroscopic work, and in bolometric or other thermal investigations of the Moon. Mechanically a short tube is advantageous on account of its rigidity and convenience.

4. *Small cost of speculum, mounting and dome.*—A perfectly figured silvered glass speculum of thirty-six inches aperture costs rather less than $2000. The objective of the Lick telescope, of the same aperture, cost $50,000, or twenty-five times as much. For larger apertures the comparison would be even more favorable to the reflector. On account of their relatively short focal length specula can ordinarily be mounted more cheaply than objectives of the same aperture. For the same reason some saving can be effected in the cost of the dome, which, when the telescope tube is mounted with the declination axis at its center, varies nearly as the square of the focal length of the telescope used under it. In the mounting of reflectors the declination axis is usually placed nearer the mirror, so that the dome must be larger than would be the case if it were central.

5. *Possible large linear aperture.*—The largest objective hitherto constructed has an aperture of one meter. Rough disks of optical glass have, I understand, been made for telescopes of larger aperture to be mounted in Berlin and Paris. In the present state of optical glass manufacture it is perhaps possible to make an objective of 150^{cm} aperture, but both the

[1] E. F. NICHOLS, *Phys. Rev.*, 4, 303, 1897.

glassmaker and the optician would regard such an undertaking as a most formidable one, requiring at least five or six years of labor for its completion. On the other hand a speculum of 180^{cm} aperture has already been made and used by the Earl of Rosse, and the St. Gobain Plate Glass Company offered in 1896 to furnish a glass disk suitable for a speculum of 220^{cm} aperture. It is not improbable that an order for a glass speculum three meters in diameter would be accepted by the glassmaker and the optician, who might be expected to complete the work within a period of two or three years. As Sir Howard Grubb has pointed out in the memoir referred to above, large disks of speculum metal would probably be easier to obtain than glass disks of the same diameter. But the latter are generally to be preferred, on account of their comparative lightness and the ease with which they may be re-silvered without the slightest danger of affecting their figure.

The above considerations seem to show that the astrophysicist may properly consider the reflector to be an even more important part of his instrumental equipment than the refractor. For many of his investigations it is indispensable, and in most cases it offers advantages which more than offset certain other advantages enjoyed by the refractor. For direct visual observations such an instrument as the forty-inch Yerkes telescope, with its superb definition, is probably far superior to any reflector in use. It follows that an observatory which is well equipped for astrophysical research should possess both refractors and reflectors, in order that all classes of work can be prosecuted in the most advantageous manner possible.

As regards the future development of telescopes in the direction of increased light-grasping power, the reflector promises far greater gains than the refractor, especially for spectroscopic work in the so-called photographic region. Indeed, it appears from an inspection of the curves in Plate III, that an increase in the aperture of an objective beyond about 350^{cm} would be attended by no gain in the intensity of the photographic image. In the case of reflectors, on the contrary, the

light-grasping power will continue indefinitely to gain with the aperture.

The great advantages for astrophysical research offered by the *equatorial coudé* reflector, invented in its original form by my late friend Arthur Cowper Ranyard, and described by Professor Wadsworth on another page, point to this instrument as one likely to prove of great service in the future. I am glad to say that Mr. Ritchey will shortly undertake, in the optical laboratory of the Yerkes Observatory, the construction of a speculum of 150^{cm} aperture, which will be provided with a mounting of this type, and devoted exclusively to investigations in astrophysics.

YERKES OBSERVATORY,
January 1897.

ON A NEW FORM OF MOUNTING FOR REFLECTING TELESCOPES DEVISED BY THE LATE ARTHUR COWPER RANYARD.

By F. L. O. WADSWORTH.

INTRODUCTION.

IN a preceding article Professor Hale has reviewed the many advantages which reflectors possess over refractors, particularly for astrophysical work. Personally, I do not think that the former can ever quite equal the performance of the latter for general visual observations, on account of the almost insurmountable difficulties in preserving the figure of the mirror under changes of temperature and changes in position; although, as I have said in a previous paper,[1] the difficulty due to the latter may be to a great extent overcome by making the specula much thicker in proportion to their diameter than has been customary heretofore, and by adopting the counterpoised support system more fully described in Mr. Ritchey's article in the present number. For measurements of position simply the reflector obviously cannot compete with the refractor, nor is there any reason why it should, since the instruments used for such measurements are never of more than what is now regarded as a very moderate size. For celestial photography the reflector is superior in the entire absence of chromatic aberration and greater light-grasping power, and some magnificent photographs, among which those of Common, Roberts, and Wilson stand preëminent, have been obtained by its use. But it is unfortunately impossible to employ it when a large field is desired; for such purposes only a photographic doublet can be used.

Since astrophysical work then offers the greatest field of usefulness for reflectors it is for such work that their mountings

[1] A Review of Professor Johnstone Stoney's article on the "Astrophysical Observatory of the Future." *Ap. J.* 4, 238.

should be primarily designed. There is no doubt that the conditions fulfilled by the cœlostat, or by the Foucault siderostat, are those most favorable for most astrophysical work, and it is on this ground that such instruments have been considered by many as more suitable than the equatorial for the use of the astrophysicist. But, as pointed out in the review already referred to, the equatorial has great advantages on the score of simplicity, ease of control, and minimum loss of light, the latter a very important consideration in the case of stellar spectroscopy. If, then, its mounting can be so designed that the observing instruments are as favorably situated as they are with a siderostat, the only possible objections to its use for all classes of work will have been removed.

The various types of reflector mountings may be divided, so far as the position of the observer or observing instrument with reference to the telescope and its mounting is concerned, into three general classes: the Newtonian, the Cassegrainian, and that class of which the recently invented *coudé* may be taken as a type, in which at least the eye end of the telescope lies in the polar axis. Of the first two forms the second is the most advantageous, because the observing instrument can be attached directly to the stiffest part of the telescope tube, *i. e.*, the support for the large mirror; but it has the disadvantage of requiring a hole through the center of the latter. The last form is the only one which realizes the conditions satisfied in the case of the siderostat; *i. e.*, of a fixed observing instrument situated in an observing room separate and distinct from the dome or space in which the telescope itself is mounted. In the case of the siderostat the axis of the observing instrument is horizontal, while in the case of the *equatorial coudé* it is inclined at an angle equal to the latitude of the place. This, however, is no great disadvantage, as in most cases it is nearly as easy to use the apparatus likely to be employed in astrophysical work in an inclined as in a horizontal position. When the rotation of the image, with respect to the observing instrument, is not detrimental, the latter may be fixed in position on a pier in the

observing room ; in other cases it may be attached to a large plate mounted on the end of the polar axis, as shown in the following figures. The great size and stiffness which can be given to this plate enables an instrument of almost any desired size and shape to be rigidly supported on the telescope. The only motion of the instrument when so mounted is one of rotation about its own axis.

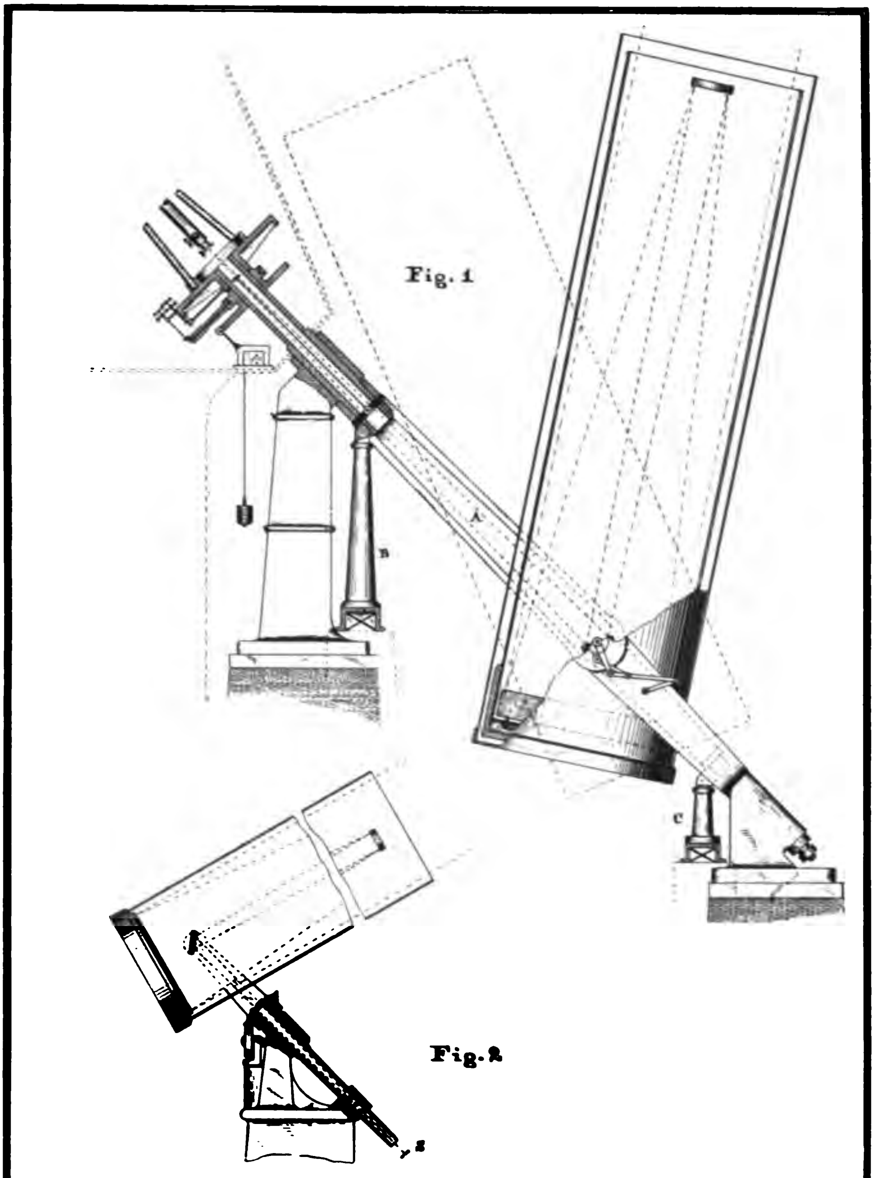
The greatest advantage of such an arrangement is the possibility of keeping the observing instrument at a constant temperature and under constant hygrometric conditions; conditions of great importance in bolometric and solar spectroscopic work, and which can never be realized in an open dome. When one reflects how much the character of an observer's work is likely to be influenced by the conditions under which he works, the minor advantages of personal comfort, and convenience of manipulation, advantages which can only be fully appreciated by those who have had an opportunity of seeing and using one of the *coudé* equatorials, are seen to be also of considerable importance.

Of the various instruments of this general type the two best known forms are the siderostatic telescope of Grubb,[1] which is simply a polar heliostat with a refracting telescope mounted in a prolongation of its polar axis and rotating with it, and the *equatorial coudé* of Loewy already alluded to.

The first has the disadvantage of having a limited range of motion in declination, the second is free from this but requires two large optical flats, each about one and one-half times the aperture of the telescope itself, one of which is in the reflector type of mounting pierced at the center by a hole of considerable size. It was probably with an idea of avoiding the expense of such a construction, while retaining all the advantages of the *coudé* mounting, that Mr. Ranyard first took up the consideration of the subject. It is the principal purpose of the present

[1] Described in the *Proc. Roy. Soc. Dublin*, 2, 362, April 1880. In a later paper (*Trans. Roy. Soc. Dublin*, 3, 61, April 1884), Grubb describes another form of mounting which may be called a dialyte *coudé*. No instrument of this form has, so far as I am aware, been built.

PLATE IV.



COUDE MOUNTINGS FOR REFLECTING TELESCOPES.

paper to decribe the beautiful form of mounting which he devised to satisfy these two conditions, and which he was prevented by his untimely death from perfecting in its minor details.

DESCRIPTION OF THE FIGURES.

Figure 1 represents in side elevation, partly in section, the original form of Ranyard's mounting, designed on as nearly as possible the original plan conceived by him and communicated to Professor Hale. The details of this mounting were never fully worked out, and had therefore to be supplied in part by the designer. Had Mr. Ranyard himself worked out the plan in full, there would probably have been less ground for criticism of many of these minor features. The polar axis of the mounting is, as will be seen, of the English form, the tube of the telescope being carried in a large closed fork, with bearings at both ends. One of the features of Ranyard's plan was to dispense with the usual dome, and replace it by a second tube parallel with and encircling the telescope tube, and moving with it, although not directly connected to it. As worked out in the present plan, this tube is carried on a fork *A* inside the main telescope fork, the declination axis being concentric with and exterior to the declination axis of the telescope itself. This fork is carried at its upper and lower ends on two pillars, *B*, *C*, which are supported on cross beams whose ends rest on two piers placed outside the two large telescope piers. These pillars, of course, prevent the complete rotation of the fork, but being narrow, allow it to swing through nearly 170°, and therefore work to within 5° of the horizon on each side.

The main feature of the Ranyard mounting is a mirror mounted in the declination axis and connected with it in such a way that it moves at half the angular speed of the latter.[1] The arrangement shown in the figure for accomplishing this is one which was designed by the writer to take the place of the usual

[1] This is also the essential feature of the dialyte *coudé* of Sir Howard Grubb, already referred to (see preceding footnote).

"minimum deviation" motion used in prism spectroscopes. It was fully described in a paper in the *Phil. Mag.* for October 1894[1]. The light from the speculum is normally reflected from a small convex mirror at the upper end of the tube, as in the ordinary Cassegrainian form, but instead of passing back through the center of the mirror, it falls upon this reflector just mentioned and by it is reflected up through the polar axis, which, as shown in the figure, is hollow. The upper end projects through the wall of the observing room, as in the *coudé* form of mounting, and to it are attached the driving-worm, the right ascension circles, and the arrangements for clamping and moving the telescope in right ascension and declination. The rods for this latter motion are carried down on one side of the opening in the axis, so as not to interfere with the cone of light.

Although the general idea of this mounting is, in my opinion, admirable, it has some few defects both of an optical and a mechanical nature, the latter of which might, as I have already said, have been avoided by Mr. Ranyard if he had carried out the design himself. Two of the greatest objections are: first, the inability to cover the entire heavens (the instrument as here designed being able to approach only to within about 25° of the pole); and second, the fact that for positions near this the line of sight is directly over the roof of the observing room and definition is likely to be seriously interfered with by the current of warm air from the latter. This last objection could be more or less done away with by making the roof of the building double and arranging for a circulation of air between the outer and the inner wall. But it will be seen that the room for this is very limited on account of the spectroscope projecting upward toward the ceiling of the room at an angle of about 45° in the present case. For lower latitudes this difficulty would of course be less.

To avoid these difficulties I have designed three modifications of the mounting, which are here presented, not because they offer a complete or fully satisfactory solution of the prob-

[1] "Fixed Arm Spectroscopes," *Phil. Mag.*, 38, 337; *A. and A.*, 13, December 1894.

lem, but in the hope that they may suggest to someone else a still better form.

In the first of these, shown in Fig. 2, the large speculum is mounted in a short, heavy fork at the upper end of the polar axis (as in the recent three-foot reflectors of Dr. Common and Lord Rosse). The small speculum and the movable reflector are mounted in the same manner as before, except that the latter is arranged to throw the light down the polar axis instead of up, and the driving-wheel, right ascension circle, clamps, spectroscope ring and observing instrument are all placed at the lower end of the axis instead of at the upper end, as in the preceding form. The whole polar axis is supported at its center of gravity on a single wheel, *A*, mounted on ball bearings, an arrangement which was suggested and described by the writer in the October number of *A. and A.* for 1894.[1]

It will be seen at once how much more advantageous this arrangement is as regards the position of the observing room with reference to the telescope itself. With this form it is only possible to sweep from the southern horizon to within about the same distance from the pole as in the preceding form, but the telescope may be revolved through 360° without interfering with any part of the mounting. It can be arranged to go even closer to the pole by making the fork longer, but this would not be worth while, as when it is necessary to examine objects close to the pole the reflector at the lower end of the tube can be raised slightly above its usual position and turned at right angles so as to throw the light along the top of the declination axis. The spectroscope or other observing instrument can then be mounted directly on the latter, as shown in Fig. 5.

With this form a greater length of flat is necessary for objects at or near the zenith, but not so great a length for objects near the horizon as in Ranyard's form. Since the major-

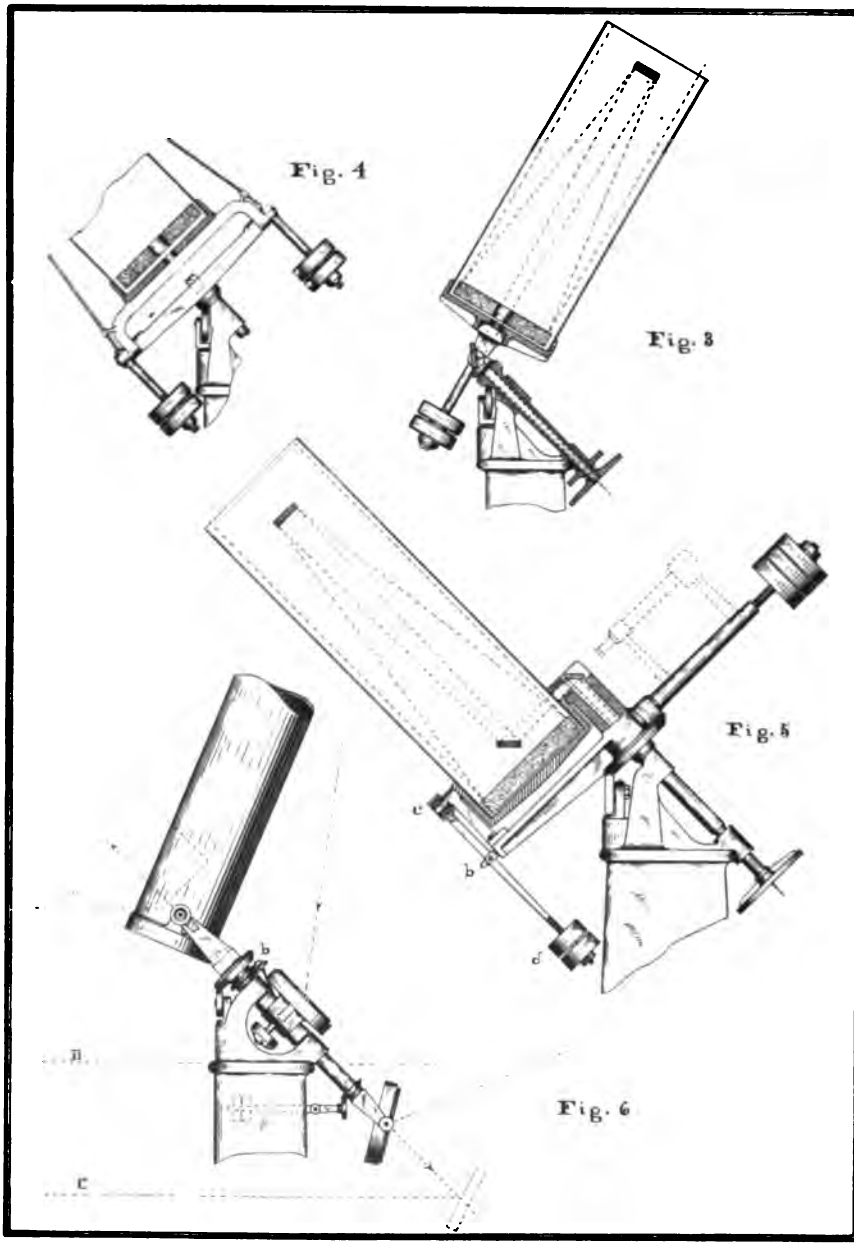
[1] I have since learned that this same device was previously used by the Repsolds in the mounting of the Pulkowa refractor. It is highly commended by Dr. Gill in the *Enc. Brit.* (see 9th ed. 22).

ity of work is done by preference on objects near the zenith, the latter has the advantage in this respect. But aside from the increased length of the reflecting surface rendered necessary, the high angle of incidence is an advantage in diminishing the effect of errors of the flat and in diminishing the loss of light by this reflection. Moreover, the distance from the flat to the focus can, as will readily be seen, be made much less than when the light is sent up the axis, and a shorter equivalent length of focus therefore obtained.

To avoid the necessity for changing the arrangement of the instrument for objects near the pole another modification of the mounting shown in Fig. 3 was devised. The arrangement is very similar to the Cassegrainian mounting except for the introduction of the reflector in the declination axis as already described. The light from the convex mirror passes through the center of the large speculum and falls on the flat, which is in this case placed behind the speculum. The form of the mounting necessary to carry out this idea is somewhat similar to the old saddleback mounting, but is much neater in general appearance, as the counterpoise weights and telescope tube are in one straight line. The fork on which the declination axis is supported is attached to the lower end of the telescope tube instead of to the upper end of the polar axis as in the preceding form, and can, as will be readily seen from Figs. 3 and 4 (the latter representing the instrument pointing directly at the pole), be made much shorter than before, while still allowing the instrument to sweep over the entire heavens. Another advantage of this reversed arrangement is that the center of gravity of the telescope, which when the instrument is in balance lies at the intersection of the declination and polar axes, is thus brought nearer the upper end of the latter.

In all the instruments so far described the flat has had to be unusually long for certain positions of the instrument, and in the case of the first two forms it has only been possible to cover a portion of the sky without rearrangement of some part of the instrument. The form next to be described avoids all of these

PLATE V.



COUDÉ MOUNTINGS FOR REFLECTING TELESCOPES.

difficulties, but only at the expense of an additional reflection. It has however the advantage of requiring no relative motion between the flat in the declination axis and the telescope tube. In measurements of position this might become of considerable importance, although if the link motion already described is used for connecting the flat with the declination axis, there is much less chance of error than in the ordinary minimum deviation motions. In this form, which is shown in Fig. 5, one reflector is arranged as before in the declination axis, but is turned at 90° to its former position so as to reflect the rays along this axis instead of along the polar axis. The second reflector is then placed at the intersection of the polar and declination axes, in such a position as to reflect the light down the latter. These two small reflectors are rigidly fixed in position with respect to the declination and polar axes respectively, and as will readily be seen, bear the same relation to each other as do the two large reflectors in the *coudé* equatorials. If desired for any particular purpose the second reflector may be removed and the spectroscope or other observing instrument mounted directly in the declination axis, as shown by the dotted lines in the figure. The arrangement for relieving the friction on the polar axis is the same as in the preceding two forms, but on account of the overhanging of the fork which carries the outer end of the declination axis in this form, a special device has been introduced for transferring about 90 per cent. of pressure from this point to another point much nearer the end of the polar axis. This is accomplished by means of a lever, which is pivoted on a ball and socket or gimbal joint at *b* and has at its upper end a ring of U shaped inner section, *c*, which surrounds the declination axis. Between each arm of the U and a steel flanged collar on the declination axis is a row of balls. On the other end of the lever is placed a weight *d* of such mass that its moment about *a* is equal to the moment of about 45 per cent. of the mass of the telescope, acting at *c*.

The remaining 5 per cent. of the pressure on the outer fork arm is easily supported by the latter even when it is compara-

tively light without danger of flexure.[1] The inner support of the declination axis is a prolongation of the polar axis itself, and is in consequence so stiff and rigid that there is no necessity of relieving the pressure upon it so far as any danger of flexure is concerned. By placing the arm which carries the counterpoise in right ascension in line with the base of the fork, the center of mass of the telescope, fork, and counterpoise weights is brought so near the end of the polar axis, that only a slight weight on the end of that axis is sufficient to bring the center of gravity of the whole revolving system directly over the friction wheel under the upper end of the polar axis. Ordinarily this weight would be furnished by the spectroscope or observing instrument attached to the lower end, so that no dead weight is really necessary.

It has not been thought necessary to show in these latter three figures the details of the slow motions, circles, etc. Their arrangement is perfectly obvious.

In this connection it may also be interesting to show a form of mounting which has suggested itself as especially adapted for astrophysical observatories, in which three separate and distinct instruments are carried on the same mounting without interfering in any way with each other. This arrangement is shown in Fig. 6. It consists of a large reflector mounted in the same way as in Fig. 5, except that the second reflector is turned through 180° so as to reflect the light up the axis instead of down. As the telescope itself is mounted to one side of the polar axis, a small observing room into which the spectroscope may project, may be built in the prolongation of this axis without interfering with the motion of the telescope, even when the latter is pointed toward the pole. The polar axis of the reflector mounting is hollow, as before, and through it projects a second axis which carries at its lower end the fork of a polar heliostat, which may be supported as shown, by a second independent friction

[1] This same method of removing the pressure from the outer ends of the fork might be used with advantage in the case of the mounting shown in Fig. 2. The fork arms could then be made much lighter than has been possible in previous mountings of this kind.

wheel placed at the center of gravity of the fork and its axis, so as to entirely relieve the friction between the two axes. The two axes may be clamped together so as to revolve as one when desired, and since one may be moved into any position with reference to the other, two entirely separate objects can be followed at the same time. Between the two forks in which the polar axis of the telescope is mounted is a sleeve having its bearing on the moving axis of the reflector, and carrying a cœlostat mirror. This is normally free on the telescope axis, but may be connected with it by gears, *b*, so as to be made to revolve with it at half the angular speed. This cœlostat mirror may then be set on any third object, and when connected as just described to the telescope axis, will of course follow this object. We have, therefore, the first instrument, viz., the reflector, with which observations are carried on on a floor *A*; a second instrument, the polar heliostat (which may if desired be replaced by any form of siderostat), with which observations are carried on at a level *C*; and the third instrument, the cœlostat, with which observations are carried on at the intermediate level *B*, each working entirely independently of the others. In the case of very large instruments the cost of the mounting, as is well known, is more than half the cost of the whole instrument, and the combination of three instruments on one mounting would therefore effect a very considerable saving in the aggregate cost of the whole combination, besides utilizing space in the observing dome to much better advantage than is usually done.

The large cost of the usual form of revolving dome compared with the cost of the instrument for whose protection it is designed raises again the question as to whether some cheaper and at the same time efficient arrangement cannot be invented to take its place. With the original *coudé* forms this dome is not necessary, or rather its place may be taken by a simple form of wind screen to insure stability in high winds.

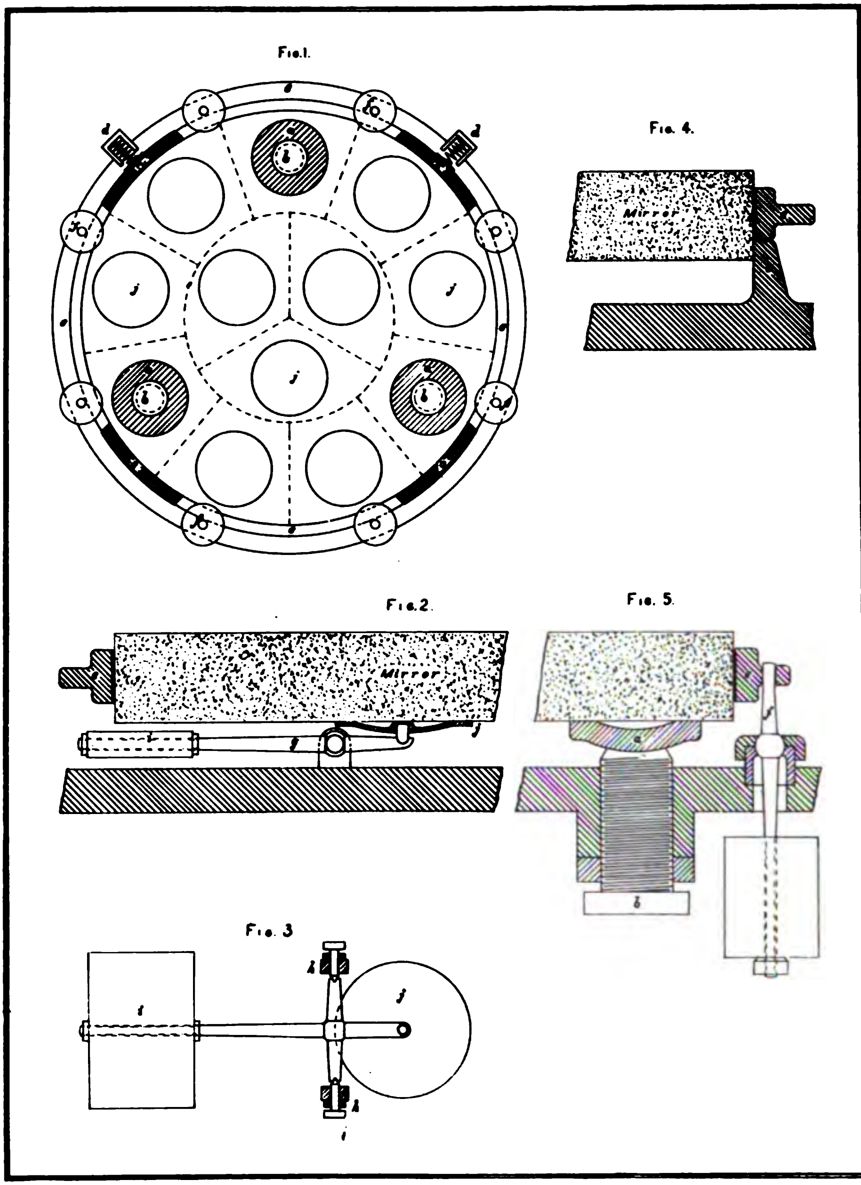
In Ranyard's form, however, something more is necessary, and his plan of using an outer protecting tube instead of a large

dome seems a step in the right direction. There are, however, great mechanical difficulties to be overcome, and the plan of mounting this tube shown in Plate IV, must be regarded as only a crude attempt to illustrate how the idea may be carried out. I have under consideration a number of other plans of protection both for these forms and for the ordinary refractor mountings (the general idea of one of these plans was sketched in a recent number of this journal),[1] but none of them have been developed sufficiently to warrant description at the present time.

YERKES OBSERVATORY,
January 1897.

[1] *Ap. J.* 4, 240.

PLATE VI.



SUPPORT SYSTEM FOR LARGE SPECULA.

A SUPPORT SYSTEM FOR LARGE SPECULA.

By G. W. RITCHEY.

IN properly supporting a large telescope mirror in its cell, to secure at once freedom from flexure and great stability of position of the mirror, a degree of care and refinement is demanded which is not necessary, to the same extent, at least, in the case of an objective; for, as is well known, flexure of a telescope mirror is directly injurious to the sharpness of the focal image, there being no inherent partial correction or compensation such as occurs in case of flexure of an objective. And there is another somewhat similar consideration: a tilting of the mirror in its cell directly affects the position of the focal image, while with an objective such a change of position is compensated for as in the case of flexure. When the mirror or objective moves in its own plane, the effect on the position of the image is direct, and is, in general, the same in both.

The beautiful mirror-support systems devised by Lassell, Grubb, Common, and others, while probably leaving little to be desired so far as supporting the mirror without flexure is concerned, certainly do not give the very great stability of position which is desirable in view of the considerations named above, and in view, also, of the fact that the most promising lines of work for the reflector are in the direction of photography and spectroscopy, in which long exposures are necessary, with the utmost attainable precision in pointing and following.

The mirror support system described below was devised for the purpose of affording a "flotation" support which would be not inferior to the best hitherto in use, and at the same time of affording a very high degree of stability of position of the mirror in its cell. It was designed by the writer many years ago, but has not hitherto been published, though the detail drawings were shown to Professor Hale in 1891.

The back support.—Let us consider the mirror to be divided into twelve imaginary segments of equal weight (see Fig. 1, Plate VI). The back of the mirror rests, primarily, upon three strong hardened steel plates, represented by the three shaded circles *a* Fig. 1, and at *a* Fig. 5, the center of each plate being directly back of the center of weight of the corresponding segment. The upper surface of each of these plates is ground to fit the back of the mirror; the lower surface is slightly convex and is ground to fit a corresponding concave in the upper end of each of the three large adjusting screws for adjusting the optical axis of the mirror, these adjusting screws projecting slightly through the massive casting which forms the mirror cell. This is shown in Fig. 5. It will be noticed that these three plates are near the edge of the mirror, in the outer ring of segments, and that the base of support is therefore much larger than in the support systems mentioned above. It is evident that by properly designing these steel plates and the adjusting screws which support them, we can fix with great stability the plane of the mirror which rests directly upon them, their being no *building out* from these three primary points of support—no intermediate levers as in the older systems.

Now the weight of the remaining nine segments of the mirror is just balanced by means of nine weighted levers, entirely independent of each other, which lie in a plane parallel to the back of the mirror. One of these levers is shown at *g* Fig. 2, and in plan in Fig. 3. These levers are suspended between pivots screwed through lugs projecting from the cell. The small cone-bearings *h* Fig. 3, are carefully made to reduce friction. The long arms of these levers carry adjustable lead weights (*i*, Figs. 2 and 3) which, in order to occupy as little space as possible perpendicular to the plane of mirror, are in the form of plates instead of cylinders; the short arms of the levers are thus made to press against the back of the corresponding segments through the medium of light plates, represented by the unshaded circles in Fig. 1 and at *j*, Fig. 2.

Let us suppose that the mirror weighs 120 pounds. With

the cell in a horizontal position the lead weight on each lever would be adjusted by means of a standard weight of ten pounds placed upon the plate on the short arm. This adjustment being completed, if the mirror be now laid upon the support system the nine levers will, of course, carry ninety pounds of the weight of the mirror, and the remaining thirty pounds will be distributed equally upon the three plates on the upper ends of the adjusting screws. Thus each of the twelve segments of the mirror, weighing ten pounds apiece, will be balanced, independently, by a pressure of ten pounds exerted directly against it from beneath. Now suppose that the edge support of the mirror, which will be described below, be introduced and the entire system inclined in any direction and at any angle. It is evident that, so far as the back support is concerned, there will still be a perfect balance maintained; and this whether the levers lie in such a direction that the vertical planes through the length of the levers are parallel to the vertical plane through the axis of the telescope tube, or not.

The edge-support.—The connection between the back-support and edge-support is so intimate that any inefficiency in the latter will effect injuriously the operation of the former, however perfect that may be in itself. In an equatorially mounted mirror, different points of the edge of the mirror become successively lowest, of course, as the position of the telescope is changed. In the flexible band and cushioned edge-support so much used in England, the heavy mirror therefore necessarily changes its position, laterally, with respect to its cell, in taking its bearing down against the edge-support; thus not only is stability lost, but this tendency to lateral shift must impair the freedom of operation of the back-support system.

In the plan under consideration four metal arcs are used (*c*, *c*, *c'*, *c'*, Fig. 1) for the purpose of fixing the position of the mirror laterally; two adjacent arcs are cast directly on the cell, as at *c*, Fig. 4; the other two, diametrically opposite these, exert a slight pressure against the edge of the mirror, by means of weak springs, for the purpose of holding it against the stationary

arcs; this pressure need amount to only a very small percentage of the weight of the mirror, for all of the lateral pressure due to the weight of the mirror, when in oblique positions, is carried by a stiff metal ring (*e*, Figs. 1 and 5) which encircles the edge of the mirror, and fits it loosely, a thin band of hard leather being inserted between the ring and glass. This ring is suspended by three short wires from the telescope tube above, so that if the mirror were removed the ring could swing freely in its own plane. This ring is pressed against the edge of the mirror, when the latter is inclined, by a series of eight short weighted levers (*f*, Figs. 1 and 5) which hang perpendicularly to the plane of the ring. These levers are suspended from the cell-plate behind the ring by means of ball-and-socket joints, or preferably, to reduce friction, on pivoted universal joints. The ends of the short upper arms of these levers fit loosely into holes in the ring; the lower ends carry lead weights, the adjustment of which, so that the eight levers will just balance the combined weight of the mirror and edge ring, is effected in a manner very similar to that described in the case of the levers for back support.

Remarks.—It will be noticed that the edge-support and back-support systems work together well. The latter is always free from the great constraint and friction which any tendency to lateral shift of the mirror would introduce.

The number of segments independently balanced by the back-support system may of course be increased in the case of very large or thin mirrors. An incidental advantage which occurs when this is done is that the base of stable support afforded by the three plates on the adjusting screws, will be still larger, compared with the size of the mirror, than when twelve segments are used.

All of the levers used in the back-support can be exactly alike, as can also the eight levers used in the edge-support; this is advantageous in point of simplicity and economy.

Since it is desirable that the mirror cell be a massive casting, to insure great rigidity, care has been taken, in designing it, to afford ample ventilation at the back of the mirror, so that front

and back of the latter shall be similarly exposed to temperature changes. The back of the mirror, as well as the face, is polished and silvered, in order that the two surfaces shall be similarly affected by such changes.

It is evident that the more perfect the "flotation" effect afforded by a support system, the thinner can the mirror be, in proportion to its diameter. The difficulties encountered in making very *thick* disks of glass which are homogeneous and thoroughly annealed, are so great that the problem of properly supporting comparatively thin mirrors becomes a most important one in the case of very large apertures.

YERKES OBSERVATORY,
January 1897.

Minor Contributions and Notes.

NOTE ON THE RANYARD MOUNTING FOR REFLECTING TELESCOPES.

In connection with Professor Wadsworth's description of a novel form of mounting for a reflecting telescope, devised by the late Arthur Cowper Ranyard, it may not be out of place to narrate here certain incidents connected with the last year of Mr. Ranyard's life which are intimately related to the subject of the paper.

In the autumn of 1893, while on the way through England to the Continent, Mr. Ranyard's kindly persuasions caused me to deviate from a direct path to Berlin in order to spend a few days with him in Paris. At the Paris Observatory we employed most of our time in examining the lunar and stellar photographs of the MM. Henry, the photographs of stellar spectra obtained by M. Deslandres with the remodelled reflector of Eichens, and the large scale photographs of the Moon, then but recently taken with the *equatorial coudé* by M. Loewy. The instruments themselves received no small share of our attention, and we were both particularly struck with the *equatorial coudé*, which in spite of its great size and weight is yet so perfectly within the control of the observer in his fixed position at the eyepiece.

During the following winter, which we passed in Berlin, I heard frequently from Mr. Ranyard, and it was planned that he should join our expedition to Mount Etna in the spring of 1894. This, unfortunately, his failing health did not permit him to do, but early in March, just before our departure for Italy, he paid us a visit of a few days in Berlin. He was naturally most anxious to see the Astrophysical Observatory at Potsdam, and we were fortunate in being able to spend some hours there with Professors Vogel and Scheiner. Naturally the discussion was confined for the most part to the beautiful photographs of stellar spectra obtained with the spectrograph attached to the 12-inch refractor. A careful examination of the original negatives with a microscope, coupled with a minute explanation of the details by Professor Vogel, produced a great impression upon Mr. Ranyard, and undoubtedly had much to do with his subsequent decision to take up

stellar spectroscopic work with a reflector. While thoroughly familiar with spectroscopic methods, and alive to the remarkable progress made in stellar spectroscopy since the pressure of duties at Lincoln's Inn and the demands of editorial work had diminished his activity as an investigator, his confidence in the high degree of accuracy recently attained in determinations of motion in the line of sight needed just such strengthening as the visit to Potsdam brought to it. The enthusiastic belief in the modern methods of stellar spectroscopy thus aroused was checked only by his death. It entered into a resolution formed when his illness was in its earlier stages, to remove from London in order to devote the major part of his time to astrophysical research. And it probably led him to devise the valuable form of mounting for a reflecting telescope described by Professor Wadsworth on another page. G. E. H.

A NOTE ON A NEW FORM OF FLUID PRISM.

I HAVE just received a letter from Lord Rayleigh in which he is kind enough to point out that the idea of making a fluid prism with a free liquid surface was suggested long ago by Brewster in his Treatise on Optics (§53, 455.) I am not surprised to hear that I have been anticipated, for, as I remarked in my paper, it would have been indeed surprising had so simple an idea not previously suggested itself to someone else. As however I had never seen it described, I thought it worth while to publish the description of it that I did. As there is unfortunately no copy of Brewster's work either in my own library or in that of the Observatory and as the nearest reference library is nearly eighty miles away, I have not yet had an opportunity to consult the reference myself and so am not sure but what Brewster suggested some better arrangement than mine. It is quite probable that he did, but even in the form in which I used it, its performance was most promising, and I think I may say as Poynting did with reference to the parallel plate micrometer: "Now that I have no claim to its invention I may perhaps fairly express the opinion that the instrument is of great value." F. L. O. WADSWORTH.

REVIEWS.

Observatory Atlas of the Moon. Lick Observatory. Published by the gift of W. W. LAW, ESQ., of New York City.

THE first sheet of an observatory atlas of the Moon, a work which when complete, will consist of sixty or more plates, with index map, etc., has been distributed by the Lick Observatory. The scale of this important photographic map is the same as that of Beer and Mädler's chart (three Paris feet or $38^{\text{in}}.36$ to the Moon's diameter), and half that of Schmidt's chart. The plate just published shows the terminator, with the Moon near the third quarter, from the south pole to about 30° south latitude. It is reproduced from the original negative by a gelatine process, which has the advantage of giving satisfactory results at a comparatively small expense; and in a work like this, requiring more than sixty different plates for its completion, the cost of the reproductions is a consideration of no small importance.

It is interesting to compare this atlas with the one just issued by the Paris Observatory, an account of which was given in the last number of the ASTROPHYSICAL JOURNAL. If we regard the plates in these two atlases as pictures, the advantage is altogether with the Paris heliogravures; they are larger, more brilliant, more impressive. But pictorial effect is evidently no just criterion of scientific value, and if we regard the atlases from the latter standpoint, we see that each has certain advantages of its own. In the Paris photographs the enlargement has, perhaps, been pushed beyond the limit of usefulness, and it would seem that everything which appears on the plates would be shown equally well if the scale were only half as great. If this is so, the impressive appearance above referred to has been gained at the expense of handiness. Further, an examination of the Lick Observatory plate shows that brilliancy of effect has been deliberately sacrificed to secure other and more solid advantages. The printing has been carried so far that details appear in even the highest lights, with the result that, while much is shown that otherwise would have been lost in the process of reproduction, scarcely any pure white is found in the picture, and a general flatness of effect is produced. Each atlas has,

therefore, its own special value. The Paris atlas will be eminently useful for consultation in its place on the library table; the Lick Observatory atlas will find its chief use in the hand of the observer at the telescope.

No information is furnished with the plates as to the manner in which the Lick negatives are obtained, although all necessary particulars will doubtless be given with the text of the completed atlas. Professor Holden has given some details of the process in a review[1] of the Paris atlas, from which it appears that the image is directly enlarged in the telescope to a diameter of twenty-six inches, and the resulting negative is then further enlarged to the scale of the plates. The difficulties attending the first part of the process are partly obviated by the use of specially sensitive dry plates, which allow the exposure times to be reduced to ten or even to five seconds. The chief advantage of this method over that of enlarging a negative obtained at the focus is, that the coarseness of grain of the dry plate becomes relatively less important. In the Paris photographs the grain is quite conspicuous, as one would expect from the great enlargement of the original negative. A fine grain which is noticeable in the Lick Observatory plates is not, according to Professor Holden, derived from the original negative, but is introduced by the process of reproduction. It is not stated with what aperture the direct enlargements were made.

It seems to the reviewer that it would be worth while (if the attempt has not already been made) to try the old wet plate process with the modern great refractors, or at least slow and fine-grained plates such as are used for lantern transparencies. When negatives of the Moon are made on quick plates in the focus of a great telescope, the best results appear to be obtained by greatly reducing the aperture; at least this is true for the Lick telescope, which gives the sharpest definition when the aperture is stopped down to about eight inches.[2] There is little doubt that this improvement is mainly owing to the fact that with the ordinary ratio of aperture to focal length, the resolution of a photographic telescope is determined by the grain of the plate, rather than by the aperture of the objective. The telescope is unnecessarily good for the plate. Hence the aperture can be reduced without injury to the definition, and an improvement will result if the reduction is attended by gain in other directions, as for example in the diminution

[1] *Pub. A. S. P.*, No. 53, 8, 319–324, 1896.

[2] *Publications of the Lick Observatory* 3, 3.

of the effects of chromatic aberration and atmospheric disturbance. Supposing atmospheric difficulties to be avoided by choosing only the finest nights for observation, should we not expect to gain in definition by using fine-grained plates, with an aperture large enough to compensate for their greater slowness by increased brightness of the image?

K.

Die Schwankungen im Wasserdampfgehalte der Atmosphäre auf Grund spectroskopischer Untersuchungen. TH. ARENDT. *Wied. Ann.*, 58, 171–204, 1896.

IN this paper the author, a member of the staff of the Prussian Meteorological Observatory at Potsdam, gives an account of his spectroscopic investigation of the variations in the amount of aqueous vapor in the atmosphere during the latter part of the summer of 1895.

The method employed was that of estimating the intensity of the aqueous vapor lines in terms of the intensity of nearly equal metallic lines in neighboring parts of the spectrum, in a manner quite analogous to Argelander's method in stellar photometry. The third-order spectrum of a plane Rowland grating was used in connection with the large spectrometer of the Potsdam Astrophysical Observatory.

Six vapor lines were selected for observation from each of two groups of atmospheric lines, the one near C and the other near D, and respectively ten and fourteen metallic comparison lines were carefully estimated until a scale, having in the two cases ranges of 22 and 29 intensity "steps," was established. The intensity of the atmospheric lines could then at any time be estimated in steps by comparison with the metallic lines of most nearly equal intensity.

The two variable groups were treated separately in the reductions, the mean of the estimates of intensity of the six lines of each group being taken to represent the absorption in each group at the time of the observation; for which the zenith distance of the Sun and the length of path of the rays were also calculated.

In order to draw inferences as to the amount of aqueous vapor present in the air, it became necessary to reduce the observations to a uniform length of path, as they had been made at altitudes of the Sun ranging from 54° to 22°. A standard length of path of 1.50 (that for the zenith being unity) was adopted, corresponding to a zenith distance of the Sun of 48°, and corrections were applied to the observed inten-

sities to reduce them to this standard. To calculate the corrections it was necessary to test the law of increase of intensity of the lines with increase of path, which from observations of Cornu and of Müller was expected to be that of direct proportionality. This was fully confirmed by series of observations on the same day at different solar altitudes.

When the intensity of the absorption is thus reduced, and compared with the absolute humidity for each date, a close accordance is found. The author rationally considers the series of observations still too brief to justify conclusions as to the meteorological conditions in inaccessible layers of the atmosphere. He confirms the results repeatedly obtained elsewhere that the transparency of the air is greatly affected by the amount of aqueous vapor present.

As to the practical use of the method in weather prediction, Dr. Arendt gives a decidedly negative opinion. It does not follow that all methods of studying the rain-band are without value in forecasting, but it is perhaps a necessary defect of a method which always requires the spectroscope to be directed toward the Sun. For most purposes it would be desirable to measure the absorption in all azimuths, and at much lower altitudes than is possible when the Sun must be directly observed; since changes in the rain-band are of course much more pronounced when the path of the rays is long, as at altitudes of 5° or 10°. For use in connection with short forecasts, the instrument devised by C. S. Cook (*Science*, **2**, 488–491, 1883; *Am. Jour.* (3), **39**, 258–268, 1890) would seem much more suitable (to one who has used it).

The procedure adopted by Dr. Arendt appears as suitable, and the results obtained as satisfactory, as those described by Jewell in a late number of this JOURNAL (**4**, 324–342), where a photographed scale was employed for comparisons of intensity. The accuracy of Argelander's method is sufficiently established in stellar photometry to warrant its extension to spectrum lines; the exercise of judgment being required in comparisons with an artificial scale quite as much as in direct estimates.

The testimony of both observers now referred to makes it evident that there is much to be improved in methods of meteorological spectroscopy, but the papers of Arendt and Jewell may be considered as reports of progress.

E. B. F.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

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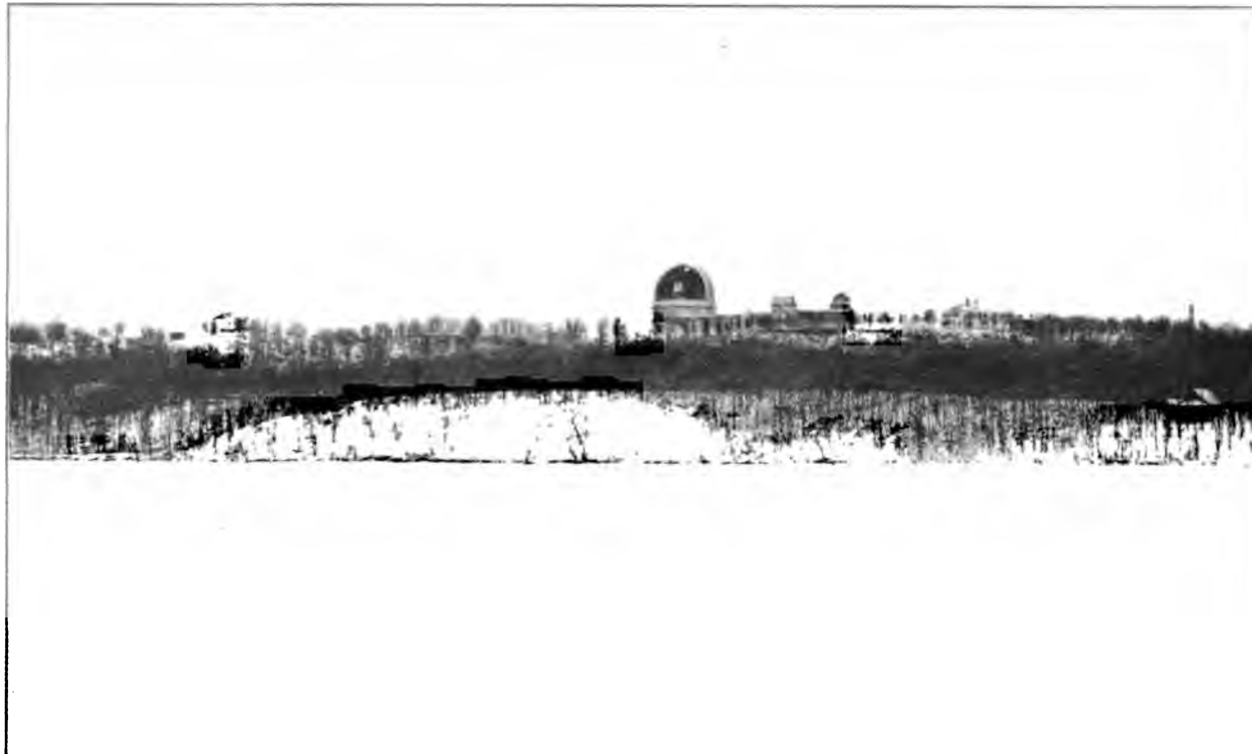
PLATE VII.



THE YERKES OBSERVATORY, AS SEEN FROM LAKE GENEVA.

FEBRUARY 1897.

THE

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RÉSUMÉ OF SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE DURING THE SECOND HALF OF 1896.

By P. TACCHINI.

I GIVE below a résumé of the solar observations made at the Royal Observatory of the Roman College during the second half of 1896. The following results have been obtained for the spots and faculæ:

1896	Number of days of observation	Relative Frequency		Relative Size		Number of spot groups per day
		of spots	of days without spots	of spots	of faculæ	
July	30	11.24	0.00	42.1	86.8	3.0
August	27	6.34	0.11	20.8	72.4	1.8
September	29	24.59	0.00	63.4	64.0	3.4
October	21	11.53	0.05	29.1	123.5	2.4
November	17	15.30	0.00	79.9	71.5	4.0
December	17	12.18	0.00	45.8	77.1	2.9

A point worthy of notice in this series of observations is the secondary minimum for the spots in the month of August, followed by a maximum, due largely to the appearance of the magnificent group visible from the 10th to the 22d of September. On September 16 this group was formed of sixteen spots and twenty-seven pores, and had an extent of 6′ parallel to the equator.

For the prominences we have obtained the following results:

1896	Number of days of observation	Prominences		
		Mean number	Mean height	Mean extent
July	30	4.26	36″.2	1°.8
August	24	4.00	34 .6	1 .1
September	26	3.77	34 .9	1 .2
October	14	6.93	38 .7	1 .6
November	9	5.56	39 .9	1 .9
December	9	3.78	39 .4	2 .0

The weather was very unfavorable for spectroscopic observations during the fourth quarter, and especially during the last two months of the year. Even in August, when the weather is ordinarily most favorable, we frequently had a bad sky.

The minimum for the prominences occurred at the time of the spot maximum, and in comparison with the preceding series it may be said that the phenomena of the prominences have remained almost stationary.

Following are the results for the distribution in latitude of the different solar phenomena, calculated for each quarter:

1896 Latitude	Prominences		Faculæ		Spots	
	Third quarter	Fourth quarter	Third quarter	Fourth quarter	Third quarter	Fourth quarter
90° + 80°	0.000	0.010				
80 + 70	0.000	0.010				
70 + 60	0.000	0.005				
60 + 50	0.042	0.047				
50 + 40	0.099 } 0.472	0.068 } 0.364	0.000			
40 + 30	0.127	0.073	0.000	0.013		
30 + 20	0.105	0.068	0.047 } 0.244	0.038 } 0.298	0.037	
20 + 10	0.062	0.052	0.090	0.120	0.182 } 0.345	0.075 } 0.200
10 + 0	0.034	0.031	0.107	0.127	0.126	0.125
0 — 10	0.082	0.094	0.146	0.196	0.182	0.200 } 0.800
10 — 20	0.130	0.120	0.276	0.253 } 0.702	0.382 } 0.655	0.600
20 — 30	0.141	0.162	0.223 } 0.756	0.190	0.021	
30 — 40	0.093	0.099	0.094	0.063		
40 — 50	0.065 } 0.528	0.099 } 0.636	0.017			
50 — 60	0.011	0.031				
60 — 70	0.006	0.016				
70 — 80	0.000	0.010				
80 — 90	0.000	0.005				

The frequency of each class of phenomena has increased in the southern zones. The prominences have been quite numerous from the equator to $\pm 50°$, as in the preceding six months. The faculæ have been confined within latitudes $\pm 40°$, and the spots within $\pm 30°$ during the third quarter and $\pm 20°$ during the fourth quarter. It must also be remarked that during the six months prominences have been seen in every zone, and very near to the poles.

The great extension in latitude and the wide zones of frequency of the prominences permit us to consider the solar corona to be more closely related to the prominences than to other solar phenomena. It follows that according to our observations the corona at the time of the last eclipse should have appeared low from the polar regions to the parallels of 60°, and clearly marked and much more extended from the equator up to $\pm 60°$, just as it is shown in such photographs and drawings as I have seen up to the present time. It therefore seems to me safe to say that the variations of the solar corona should be in accord with those of the prominences.

ROME, January 30, 1897.

OXYGEN IN THE SUN.

By ARTHUR SCHUSTER.

IN an important communication printed in the current number of the ASTROPHYSICAL JOURNAL (December 1896) Professors Runge and Paschen give strong evidence that one of the triplets of the spectrum, which I have called the "compound line spectrum" of oxygen, appears in the Sun. The question whether the lines of this spectrum coincide with dark solar lines was discussed by myself nearly twenty years ago (*Nature*, Dec. 20, 1877), and I then gave what at that time seemed to me to be the evidence in favor of its presence. But the resolving power used was inadequate, for the triplets were observed as single, their triplet nature being discovered later by Piazzi Smyth. As a matter of history I may quote the remarks made by this eminent spectroscopist on the solar coincidences with the compound line spectrum of oxygen. After referring to my own work on the subject he writes (*Trans. R. Soc. Edinburgh*, Vol. XXX, Part I) "In apparently the very place of the three fainter of the above described divided triplets there is a close double of peculiarly thin Fraunhofer lines depicted by Professor Angström in his normal solar spectrum map; and in the place of the brightest of them, viz., Schuster's orange line, there is a triple of the same kind of ultra thin lines; and not one member of all those four groups has been claimed for any known element by the great Swedish physicist. Yet I am by no means satisfied that the degree of correspondence is conclusive; and can only hope that those who have the means will positively confront the new oxygen triples with the Sun itself, and inform us what they find." Nothing further was done on the subject until Runge and Paschen took the matter up, and gave additional weight to the probability of the presence of oxygen in the Sun. The coincidence they point out does not refer to any of the triplets which Piazzi Smyth mentions in the above quotation, but to one which lies in the red. The reason why I have referred to my

own contribution to the subject is not that I attach any weight to it (on the contrary, it is quite clear now that I could not with the dispersion I used institute any satisfactory comparison) but that in my letter to *Nature* to which reference has been made, I drew attention to one circumstance which seems to me to deserve the serious attention of those who have the necessary instruments at their disposal. This is the fact that Young gives in his list of chromospheric lines, observed at a height of 8300 feet, two lines having wave-lengths of 5435.4 and 5329.1, in Ångström's scale, the frequency of the first being given as 5, that of the second as 6. These lines are sufficiently near two of the oxygen triplets to make it desirable to ascertain their wave-lengths more closely, and especially to determine whether the chromospheric lines are not in reality close triplets. Without knowing that Runge and Paschen were engaged on this question I recently examined the oxygen spectrum with a Rowland concave grating in order to determine the wave-lengths more accurately. The wave-lengths for the more refrangible of the above triplets which I have obtained are on Rowland's scale

5330.793 5329.827 5329.293

I do not however wish to consider these numbers as final, as they are only the result of one series of measurements. There are two lines on Rowland's list (5329.329, 5329.975), which are very near the two strongest components of the triplet, but they are assigned to chromium, and if the oxygen lines are really in the Sun they would probably be hidden by these chromium lines. Rowland also gives a weak line corresponding to the weakest and least refrangible component of the triplet, 5330.748. So far then as this triplet is concerned the solar coincidence can neither be affirmed nor denied, but if the chromospheric line is really triple and in agreement with the members given, the presence of oxygen in the Sun would be proved beyond doubt. In view of the great importance of this subject in all problems referring to the constitution of the Sun, I may perhaps be allowed to urge the full investigation of this question on those who are working under sufficiently pure atmospheric conditions.

MANCHESTER, January 31, 1897.

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

I. SELECTION OF THE SITE.

By GEORGE E. HALE.

INTRODUCTION.

WHEN The University of Chicago commenced its work in the autumn of 1892 it was but poorly equipped for investigation in astronomy and astrophysics. The twelve-inch telescope and other apparatus of the Kenwood Observatory, though admirably adapted for certain kinds of astrophysical research, were useless in many fields of investigation which The University desired to enter. It was consequently felt that an effort should be made to provide The University with an observatory of the first class, equipped with facilities for observational and experimental work in all branches of astronomy and astrophysics.

In September, 1892, Mr. Charles T. Yerkes of Chicago, a gentleman widely known for his liberal encouragement of art, offered to purchase for The University of Chicago a pair of disks of optical glass 42 inches in diameter, by Mantois of Paris, which were then in the workshop of Mr. Alvan G. Clark at Cambridgeport, Mass. An opportunity to purchase such large and perfect disks is naturally a most exceptional one, arising in this instance from certain complications, which prevented an institution in southern California from carrying out its plan of establishing a large telescope in the vicinity of Pasadena. Mr. Yerkes' generous offer to The University, which included the assumption of the entire cost of building an equatorial refractor of forty inches aperture and housing it in a suitable observatory, was received with great satisfaction and accepted immediately. After the object-glass had been ordered from Mr. Clark, and a contract for the equatorial mounting had been made with Messrs. Warner and Swasey, the question of selecting a suitable site for the Observatory was taken up for consideration.

CONSIDERATIONS REGARDING THE CHOICE OF A SITE FOR AN ASTRONOMICAL OBSERVATORY.

In choosing an observatory site both general and special hindrances to observational work must be given consideration. In general, it is desirable to avoid localities where the mean annual cloudiness is high, or where much difficulty is likely to be experienced from wind, dust, or dew. The special requirements of the particular observations comprised in the Observatory's plan of work should next receive attention. In the following table, which has been prepared with the assistance of Professors Barnard and Wadsworth, I have indicated by the letters *A*, *B*, and *C* the approximate degree of excellence required in the "seeing," transparency of the atmosphere, blackness of the sky, and steadiness of the instruments, for various classes of astronomical and astrophysical work. In each case *A* indicates that the particular condition to which it refers should be the very best possible; *B*, that it should be fair to good; *C*, that it need be only fair, or may even be distinctly bad without materially affecting the quality of the work. Ordinarily the letters in the fourth column refer to the required degree of steadiness of the telescope or principal observing instrument. When a second accented letter is given it refers to the conditions required for a galvanometer or other similar apparatus. On account of the dependence of the blackness of the sky upon the transparency of the atmosphere, columns two and three might ordinarily be united. But the presence of fine dust in the atmosphere, while it increases the brightness of the sky to the eye, has little effect upon its transparency for the longer waves. Thus the conditions may frequently differ for spectroscopic work in the less refrangible region.

This grouping of familiar facts may be of service in emphasizing the diversity of conditions under which various classes of astronomical and astrophysical observations can be successfully made. It is evident that if the work of an observatory be chosen so as to harmonize with its environment, many results of great value may be obtained in localities which would generally be regarded as unfavorable. In the heart of a smoky city,

	Seeing	Trans-parency of atmosphere	Blackness of sky	Steadiness of instrument
Stars.				
Micrometric observations of double stars	A	B	B	A
Meridian observations:				
With meridian circle	A	C	C	A
With transit (time determinations)	B	C	C	B
Photography:				
With long focus telescope	A	B	B	A
With short focus telescope	B to C	A	A	B
Spectroscopy	A to B	B	B to C	B
Spectrography	B	B	B to C	B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B	B	B
Nebulæ.				
Discovery	B	A	A	C
Micrometric measures	B	A	A	A to B
Photography:				
With long focus telescope	B	A	A	A
With short focus telescope	C	A	A	B
Spectroscopy and spectrography	C	B	B	B
Photometry:				
Absolute measures	B to C	A	A	B
Differential measures	B to C	B	B	B
Moon, Bright Planets and Bright Satellites.				
Micrometric measures	A	C	C	A
Meridian observations	B	B	B	A
Photography	A	B	B	A to B
Spectroscopy and spectrography:				
Of general light	C	B to C	B to C	B
Of details	A to B	B to C	B to C	A to B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B	B	B
Observations of details	A	C	C	A to B
Asteroids, Faint Planets, and Faint Satellites.				
Discovery	A to B	A	A	A to B
Micrometric measures	A	B	B	A
Photography	A to B	A	A	A to B
Spectroscopy and spectrography	B	A	A to B	B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B	B	B
Observations of details	A	A to B	A to B	B
Comets.				
Discovery	B to C	A	A	C
Micrometric measures	B	B	B	A to B
Photography	B to C	A	A	B
Spectroscopy and spectrography	C	B	B	B to C

	Seeing	Transparency of atmosphere	Blackness of sky	Steadiness of instrument
COMETS.				
Photometry.				
Absolute measures	C	A	A	B
Differential measures	C	B to C	B to C	B
SUN.				
Photosphere.				
Micrometric measures, visual and photographic observations of structure	A	C	C	A to B
Meridian observations	A	C	B	A
Photography, for measurement	A to B	B	B	A to B
Spectroscopy and spectrography:				
Of general light	C	C	C	B
Of details	A to B	C	C	A to B
Photometry of general light:				
Absolute measures	C	A	A	C
Differential measures	C	B to C	B to C	C
Heat radiation with thermopile, bolometer, or radio-micrometer:				
Absolute measures	C	A	A	CA
Differential measures	C	B to C	B to C	CA
Sun-Spots and Faculæ.				
Micrometric measures and visual observations of structure	A	C	C	A to B
Photography:				
Large scale, for details	A	C	C	B
Small scale, for positions	B	C	C	B to C
Of faculæ, with spectroheliograph	B	B	B	A to B
Spectroscopy and spectrography	B	B	B	B
Photometry:				
Absolute measures	B	A	A	B
Differential measures	B	B to C	B to C	B
Heat radiations, with thermopile, bolometer, or radio-micrometer:				
Absolute measures	B	A	A	BA
Differential measures	B	B	B	BA
Heat measures in spectrum	C	A to B	C	CA
Chromosphere and Prominences.				
Micrometric measures and observations of structure:				
Visual, with spectroscope	A	B	A	A to B
Photographic, with spectroheliograph	A to B	A	A	A to B
Spectroscopy and spectrography:				
Of prominences	B	A to B	A	B
Of chromosphere	A	A to B	A	A to B

illuminated by electric lights, where the sky is bright both day and night, delicate observations of chromospheric details, faint nebulæ and comets could not be advantageously made, nor could long exposure photographs of stars be taken. But even under such circumstances the staff of an observatory need not be idle. Observations of planets, satellites and double stars, spectroscopic studies of the stars, the solar photosphere, spots and faculæ, could be prosecuted, in most cases without serious hindrance from the surroundings. In fact, it would appear that certain observations could be made to the very best advantage under just such conditions, for the most successful existing records of the detailed structure of the solar photosphere and spots were obtained by Professor Langley at the Allegheny Observatory, in the midst of one of the smokiest districts of the United States. It is, indeed, a well-known fact that the presence in the atmosphere of a dense veil of smoke or haze is frequently accompanied by the most perfect seeing. It may be added that a very large proportion of Professor Burnham's double star discoveries and measures were made in Chicago, beginning with a six-inch telescope and concluding with the Dearborn refractor of 18½ inches aperture.

But while such considerations must affect existing institutions in their choice of work, the center of a city would certainly not be selected as the site of an observatory equipped for research in fields other than those just enumerated. Nor, in general, would a mountain peak. For notwithstanding a widespread impression to the contrary, the excellent atmospheric conditions enjoyed at the Lick Observatory do not seem to be common to all mountain summits.[1] So far as Professor Keeler and I could judge from observations made during our two weeks' stay on the summit of Pike's Peak (14,147 feet) in 1893, this would be an altogether unsuitable site for an observatory.[2] In 1894 I spent

[1] See Professor Holden's interesting memoir on "Mountain Observatories in America and Europe" (Smithsonian Miscellaneous Collections, No. 1035), which has come into my hands since this article was put in type.

[2] *A. and A.*, 13, 679, 1894.

a week with Professor Riccò at the Observatory on Mt. Etna (9800 feet). Here the atmospheric conditions are affected by the neighborhood of the great crater, when the wind blows the heated air and sulphurous fumes toward the east. But with the wind in other quarters the seeing at night is sometimes very fine. However, the air currents rising from the heated mountain slopes soon after sunrise spoil the seeing, so that solar observations must be made when the Sun is hardly out of the haze which enshrouds the Calabrian coasts.[1] Professor Swift considers the seeing by no means good at the Mt. Lowe Observatory in southern California. At the Pic du Midi Observatory (9590 feet) MM. Thollon and Trépied[2] found the seeing in 1883 to be good at night, excellent shortly after sunrise while the Sun was still low, and very bad during the rest of the day. At Mt. Hamilton the day seeing is ordinarily bad,[3] but at night the atmospheric conditions appear to be unsurpassed. In general it may be said that while mountain observatories frequently enjoy the advantage of a blue sky during the day, they ordinarily suffer the disadvantage of poor seeing after the early morning hours. In some cases, as at the Lick Observatory, the seeing by night is excellent. In other cases it is worse than that found at lower levels.

It would appear that the best seeing should be found on an extensive plateau. The conditions for solar work would probably be best if the plateau were covered with a dense forest, shielding the surface of the earth from the direct rays of the Sun, and greatly reducing the radiation of heat from the soil.

SELECTION OF THE SITE OF THE YERKES OBSERVATORY.

The principal investigations to be made at the Yerkes Observatory, as outlined in the plan of work drawn up by the writer in 1892,[4] are intended to include solar observations, compris-

[1] *Ibid.*, p. 685. [2] *C. R.*, 97, 834, 1883.

[3] A recently published photograph of a Sun-spot made at the Lick Observatory seems to indicate that the day seeing is sometimes good. (*Pub. A. S. P.*, 9, No. 54, 1897.)

[4] *A. and A.*, 11, 791, 1892.

ing visual and photographic studies of the structure of the photosphere, spots and faculæ, photography of the faculæ, chromosphere and prominences with the spectroheliograph, spectroscopic observations, both visual and photographic, of all classes of solar phenomena, and bolometric and photometric investigations of various kinds; micrometric observations of double stars, nebulæ, planets, satellites, comets, etc.; photography of the Milky Way, stars, nebulæ, etc.; researches in stellar spectroscopy; meridian observations;[1] laboratory work of various kinds, principally with the spectroscope, bolometer and refractometer.[2] It is evident that in these various classes of work the greater part do not require very good seeing; but on account of the importance of the double star observations, and those of planets, satellites, the structure of the solar photosphere, etc., it was eminently desirable to choose a site at which the seeing would

[1] For the present to be confined mainly to time determinations.

[2] To form an idea of the minimum average conditions of seeing, transparency and blackness of the sky, and steadiness of the instruments permissible at a given observatory, the amount of time devoted to each class of work may be taken to indicate roughly the influence which the conditions required for these observations will have in deducing the average. It is practically impossible to determine the *value* of one class of work as compared with another, and a time basis, therefore, seems to be the only one that can be used. Times having been assigned in this way, as illustrated in the following example for the Yerkes Observatory, the averages may be taken at once. Such averages, while perhaps of no great value, at least indicate in a general way the nature of the conditions required. If, for example, the result *B* is obtained for the required average seeing, this of course does not mean that a site having an average seeing *A* would not offer greater advantages, but simply that with this minimum value the greater part of the observatory's work could be done without appreciable hindrance from atmospheric disturbance. It should be noted that, if few observations requiring seeing *A* are to be made, the difficulty of choosing a suitable site will be greatly decreased, for at most places good seeing is at least occasionally found.

Rough estimates of the relative amounts of time to be devoted each week at the Yerkes Observatory to the various classes of observations give: solar observations (three telescopes) 12; double stars (one telescope) 2; planets, satellites, comets, etc. (two telescopes) 5; stellar photography (portrait lens) 2; stellar spectrography (one telescope) 3; time service (transit) 1. Subdividing these classes of work still further, taking the corresponding data from the table, applying the proper times in place of weights and averaging, we have for the required minimum average conditions: Seeing, *B*. Transparency of atmosphere, *B*. Blackness of sky, *B*. Steadiness of instruments, *A* to *B*.

be the best attainable both by night and by day. Some of the other researches demand a dark sky and great transparency of the atmosphere, while for still others the principal requisite is complete protection of the instruments from vibrations of any kind. If there had been absolute freedom of choice, a site combining the excellent conditions for night work enjoyed at Mt. Hamilton with the good day seeing existing elsewhere would have been sought far and wide, without regard to geographical boundaries.

The practical choice of the site was materially influenced by the location of The University of Chicago. It was clearly understood by the members of The University Board of Trustees that if the Observatory were established upon The University campus there would be no possibility of entering successfully many of these important fields of investigation, and that a site must consequently be found outside the city of Chicago. At the same time the opinion was general that the Observatory could not be placed at a distance much greater than 100 miles from the city, without materially affecting its value as one of the departments of The University. There is no reason to suppose that the atmospheric conditions which prevail within a circle of this radius, with its center at Chicago, are surpassed by those existing at any point within a concentric circle having a radius of at least 500, perhaps even 1000 miles. Except in the case of the Lick Observatory,[1] which is about eighty miles by railway and carriage road from the University of California, all university observatories are located within a few miles of the other buildings of the institution. Harvard University has established a permanent observatory in Peru, but the principal observatory of the University is in Cambridge. If a university wishes to avail itself of the peculiar conditions existing in remote regions, it may do so by sending out expeditions or establishing branch observatories. It was believed that, in general, the principal observatory would be most advantageously situated if at no

[1] The site on Mt. Hamilton was selected before the Observatory entered into its present relationship with the University of California.

very great distance from the research laboratories of other departments.

As soon as it became generally known that the Yerkes Observatory was to be established outside the city of Chicago, numerous offers of land were made and other inducements were held out by individuals and by towns in various parts of the country. The offers included tracts of land in or near the towns of Morgan Park, Tracy, Highland Park, Downer's Grove, Hinsdale, Mt. Pleasant, Western Springs, La Grange, Glen Ellyn, Elmhurst, Elgin, Rockford, Peoria, Aurora, Waukegan, Belvidere, Sycamore, Marengo, Lena, Kankakee, Warren, Oregon, Princeton, Dixon, and Freeport in the state of Illinois; Lake Geneva in Wisconsin, and Pasadena in California. In company with a committee of the Board of Trustees the writer visited many of these places, and inspected the proffered sites. It soon became evident that the various tracts of land could be roughly classified as follows: (1) those in the suburbs of Chicago or other manufacturing cities; (2) those beyond the immediate suburbs, but situated at points where factories were likely to be established; (3) those situated where factories did not then exist, and were not likely to be established, near the shore of Lake Michigan; (4) those situated where factories did not then exist, and were not likely to be established, away from the vicinity of Lake Michigan. In order to assist in forming a correct estimate of the effect of smoke, electric lights, heated air, the jar produced by passing trains, and the neighborhood of a large body of water, upon the performance of the forty-inch telescope, I prepared a series of questions which were sent to Professors Barnard, Burnham, Hastings, Hough, Keeler, Langley, Newcomb, Pickering, and Young. The following abstracts of the replies received were embodied, with the conclusions which I have drawn from them, in a report presented to the Board of Trustees of The University of Chicago, on March 27, 1893. I may be permitted to express at this time the thanks of the Yerkes Observatory for these replies, as well as for the kindness of their authors in permitting them to be published.

QUESTION (1).

What do you consider the maximum distance at which a city like Chicago would appreciably affect observations with a forty-inch refractor?

ABSTRACTS OF REPLIES.[1]

I should regard a distance of ten miles as entirely outside the influence of the city dust and smoke.— *G. W. Hough.*

Evil effects of bodies of water, heated air and jar are entirely unnoticeable except in extreme cases. Smoke and electric lights more serious drawbacks, and city would produce injurious effect as far as these could be felt.— *Simon Newcomb.*

Depends in part on prevailing winds. Perhaps ten miles.— *S. P. Langley.*

Two miles if in direction of prevailing winds. Ten miles from borders of city if no prevailing wind. Should not be north of city.— *J. E. Keeler.*

Electric lights ten miles. Smoke perhaps five miles. Other causes one or two miles.—*E. C. Pickering.*

Twelve miles as good as sixty.— *S. W. Burnham.*

Uncertain. Perhaps ten miles, though electric lights might be felt further.— *C. A. Young.*

CONCLUSIONS.

A site not less than ten miles from the boundaries of the city should therefore be selected. Allowance must be also made for the future growth of the city.— *G. E. Hale.*

QUESTION (2).

What disadvantage arising from the proximity of Chicago would you consider most serious —smoke, electric lights, heated air, dust, jar or other?

ABSTRACTS OF REPLIES.

Smoke and electric lights.— *G. W. Hough.*

Smoke and electric lights decidedly. I do not suppose that heated air, dust or jar would produce any injurious effect.— *Simon Newcomb.*

Smoke and dust with irregular hot air currents.— *S. P. Langley.*

Smoke.— *J. E. Keeler.*

Smoke and electric lights.— *S. W. Burnham.*

Smoke and electric lights.— *C. A. Young.*

[1] Professor Barnard's replies were not received in time to incorporate them into the report.

Depends on kind of work. For faint objects electric lights would be chief hindrance.— *E. C. Pickering.*

CONCLUSION.

Sites in the vicinity of factories or electric lights must be avoided.— *G. E. Hale.*

QUESTION (3).

Do you consider that the proximity of Lake Michigan would affect the seeing in any way?

ABSTRACTS OF REPLIES.

Cannot state definitely. I consider that the seeing at Evanston, on the shore of the lake, will compare favorably with that at any place in the eastern part of the United States.— *G. W. Hough.*

Do not know that any affect has ever been noticed.— *Simon Newcomb.*

Cannot say.— *S. P. Langley.*

Yes, probably.— *J. E. Keeler.*

Nothing is certainly known, but some bad effect would naturally be expected.— *E. C. Pickering.*

Would expect to have more nights with the best definition at points removed from the lake shore.— *S. W. Burnham.*

Presume it would, but would not venture to predict in what way. It might do as much good as harm taking the year through.— *C. A. Young.*

My experience goes to show the beneficial effect of a neighboring great body of water. Whether Lake Michigan could be considered of importance from this point of view I am unable to say.— *C. S. Hastings.*

QUESTION (4).

If so, would this effect differ in amount at points one hundred feet and twenty miles from the lake, respectively?

ABSTRACTS OF REPLIES.

Ten miles inland annual temperature curve is a number of degrees higher in summer and lower in winter than in immediate vicinity of lake shore. Atmospheric conditions hence somewhat different, but cannot say whether better or worse.— *G. W. Hough.*

Sufficiently answered under (3).— *Simon Newcomb.*

If there is any disturbance I should think there would be a difference.— *S. P. Langley.*

At a distance of twenty miles it seems probable that the influence of the lake would cease to be felt.—*J. E. Keeler.*

Probably there would be a decided difference in favor of the remote station.—*E. C. Pickering.*

One would expect that greatest disturbance due to intermingling of air over lake and land would occur near the line joining land and water.—*S W. Burnham.*

I should think it would. So far as *general* meteorological influence is concerned there would be little difference; but any special local effect of moisture in the air would be much more powerful within a mile of the lake than at a greater distance.—*C. A. Young.*

CONCLUSIONS.

Reports obtained from Professor Mark W. Harrington, Chief of the Weather Bureau, show the average annual cloudiness at three lake ports to be:—Chicago, 51 per cent., Milwaukee, 54 per cent., Grand Haven, 58 per cent. At a point forty-seven miles from Lake Michigan the average annual cloudiness, as learned from the same source, is only 47 per cent. Therefore, on account of the increased cloudiness, and the possibility of injury to the seeing arising from proximity to so large a body of water, no site within twenty miles of Lake Michigan should be selected.—*G. E. Hale.*

QUESTION (5).

Do you consider that the certainty of having an absolutely unobstructed sky over an angle of 180° would compensate for any disadvantage which might result from the close proximity of the lake?

ABSTRACTS OF REPLIES.

The lake horizon is of minor importance, as no useful observations can be made below an altitude of about fifteen degrees.—*G. W. Hough.*

Under no circumstances can good observations be made with a large instrument near the horizon.—*Simon Newcomb.*

I cannot answer as to this.—*S. P. Langley.*

No, I see no particular advantage in having a clear horizon.—*J. E Keeler.*

No, for observations near the horizon could seldom be required.—*E. C. Pickering.*

I do not consider a clear horizon all round to be a matter of much importance.—*S. W. Burnham.*

Certainly it would be a compensation to a certain extent. But if the proximity of the lake is seriously mischievous the extended view would not make up for it.— *C. A. Young.*

No.— *C. S. Hastings.*

CONCLUSIONS.

A site on the shore of the lake would have no advantage on account of the unobstructed easterly horizon. The certainty that no factories or buildings could ever be erected in the direction of the lake would be a distinct advantage, but not a sufficient one to compensate for the increased cloudiness as compared with an inland point.— *G. E. Hale.*

QUESTION (6).

At what maximum distance would an ordinary dwelling house interfere with observations with the forty-inch telescope?

ABSTRACTS OF REPLIES.

Single dwelling house at 200 feet distance would not sensibly affect the seeing, but it would not be admissable to surround the observatory with buildings at that minimum distance.— *G. W. Hough.*

Dwelling would not sensibly interfere at distance of 100 yards, unless telescope chanced to point directly over chimney.— *Simon Newcomb.*

An affair of prevailing winds. I should prefer to see none within one-half mile.— *S. P. Langley.*

At Mount Hamilton dwelling produces no injurious effect at distance of 100 yards.— *J. E. Keeler.*

One hundred yards.— *E. C. Pickering.*

An ordinary dwelling, or dwellings, as they would be placed with reference to this or any other observatory, would have no effect upon the atmospheric conditions.— *S. W. Burnham.*

Five hundred feet (?); am not sure.— *C. A. Young.*

CONCLUSIONS.

The observatory should stand in the center of a piece of land at least twenty acres in extent, from which all other buildings are excluded. To provide for future extensions it would be very desirable to devote not less than forty acres to the exclusive use of the observatory.— *G. E. Hale.*

QUESTION (7).

At what maximum distance would the jar of railroad trains interfere with observations with the forty-inch telescope?

ABSTRACTS OF REPLIES.

On sand or gravel a distance of 2000 feet from the railroad would be desirable. On clay or limestone jar may be sensible for a mile.—*G. W. Hough.*

Railway trains interfere with observations by reflection from mercury up to a distance of one and perhaps even one and one-half kilometers. Shaking of telescope would probably not be noticed at distance greater than 500 meters.—*Simon Newcomb.*

Depends on nature of underlying strata. With certain rock strata, at a very considerable distance, *e. g.*, several miles.—*S. P. Langley.*

It would be desirable to keep at least a quarter of a mile away from any railroad. Wind is much more serious.—*J. E. Keeler.*

Half a mile, but much depends upon the nature of the ground.—*E. C. Pickering.*

The passing by of railroad trains would be no objection to the use of this or any other telescope. A small puff of wind would produce more vibration than any number of railroads.—*S. W. Burnham.*

Quarter to half a mile, unless on a rocky ledge.—*C. A. Young.*

CONCLUSIONS.

The observatory should be situated at least half a mile from any railroad. Underlying strata of sand or gravel are most suitable. Rock should be avoided.—*G. E. Hale.*

ADDITIONAL REMARKS AND SUGGESTIONS.

To be of the greatest benefit to science the telescope should be mounted at some such point as Mt. Hamilton, California; Arequipa, Peru; or the Peak of Teneriffe.—*Simon Newcomb.*

In the absence of local knowledge the opinions I have expressed cannot be regarded as having great weight. They might be seriously modified by an examination of the peculiarities of the place.—*E. C. Pickering.*

I should select a point in a westerly direction from the city, and not more than twenty miles distant. Such a place can easily be found near some one of the numerous railroads, and be conveniently accessible at all times of day and night. This is a matter of much importance in the practical working of the observatory, and should not be overlooked.—*S. W. Burnham.*

The adoption of the conclusions arrived at by the writer after careful consideration of these replies led to the imme-

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3572.460		0000	3578.530	Fe	4
3572.617		4	3578.702		0
3572.712	-,Sc	6	3578.832	Cr	10
3572.890	Cr?	00	3578.978		000
3573.017		0000 N	3579.047	Co	0
3573.087		0000 N	3579.122		00
3573.207	Fe	1·N	3579.185		00
3573.320		0000	3579.268		0000 N
3573.417		0000	3579.508		000 N
3573.540	Fe	2	3579.648		0000
3573.650		0000	3579.702		1
3573.792	Ti	2	3579.812		0000
3573.874	Fe	3	3579.974		2
3573.975	Fe	3	3580.098		000 N
3574.050		2	3580.227		00
3574.135		0	3580.356		1 N
3574.174		0	3580.552		1
3574.297		0000	3580.682		1 N
3574.394	Ti	0	3580.898		0 N
3574.499		000	3581.067		5
3574.559	La	1	3581.184		1
3574.723		0000 N	3581.349 s	Fe	30
3574.944	Cr	0	3581.531		1
3575.106	Cr-Co	5	3581.617		0
3575.260	Fe	3	3581.805	Fe	2
3575.391	Fe	3	3581.957	Fe	2
3575.494	Fe	2	3582.081		1
3575.533	Co	2	3582.231		00
3575.699		000	3582.345	Fe	5
3575.904	Zr	00	3582.471		2
3576.118	Fe	4	3582.577		000
3576.296		0000	3582.711	Fe	2
3576.393		0000	3582.838	Fe	3
3576.469		4	3582.884		00
3576.527	-,Sc?	3	3583.017		0000
3576.739		0000	3583.104		000
3576.906	Fe	2	3583.244		0000
3577.003	Zr	1	3583.357		000
3577.099		0000	3583.481 s	Fe	5
3577.203		000	3583.581		0000
3577.299		000	3583.637		0000
3577.384	Co	1	3583.737		0000
3577.532		000	3583.837	-,C	3
3577.605		1	3584.051	-,C	3
3577.705		0000	3584.147		0000
3577.885		0000	3584.237		0000
3578.014	Mn	5	3584.397		0000
3578.138		0000	3584.457		000
3578.240	Co	1	3584.523		0000
3578.358	Ti	00	3584.616		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3584.660 s	Y	2	3590.803	Fe	00
3584.800	Fe	6	3590.976		0000 N
3584.940	Co	5	3591.149	Fe	1
3585.105	Fe	6	3591.283		0000
3585.214		000	3591.366		0000
3585.310	Co	5	3591.496	Fe	2
3585.479	Fe	7	3591.629	Fe	2
3585.658		2	3591.732		0000
3585.777		000 N	3591.885		0000 N
3585.859	Fe	6	3592.045		0000 N
3585.984 s [1]	C	0	3592.169	V?	2
3586.047 s	C	00	3592.348		0000
3586.157	Co	1	3592.412		000
3586.268	Fe	4	3592.508		0000
3586.390		000	3592.619	Fe	1
3586.494		00	3592.745		000
3586.624		0000	3592.819	Fe	3
3586.684	Mn	4	3592.935		0000
3586.890		3	3593.040	Y	0
3587.024		0	3593.158		0000
3587.130	Fe	8	3593.223		0
3587.286	Ti	2	3593.402		000
3587.370	Co	7	3593.481	Fe	3
3587.497		000	3593.636	Cr	9
3587.574	Fe	3	3593.835		000
3587.757	C	0000 N	3593.935		000
3587.899	Fe	5	3594.138		000 N
3588.084	Ni	6	3594.245		000
3588.263	C	000	3594.458		0000
3588.387		0	3594.528		0000
3588.466	C	00	3594.784	Fe	6
3588.563		0000	3595.017	Co	3
3588.675		3	3595.161		0000
3588.763	Fe	4	3595.256	Mn	1
3588.916	C	0000	3595.449	Fe, Ti	2
3589.065	Fe, C	2	3595.554		0000
3589.253	Fe	4	3595.681		0000 N
3589.363	C	0000	3595.824		000
3589.446	C	000	3596.012	Fe	1
3589.601	Fe	2	3596.195	Ti	4
3589.773		5	3596.346	Fe	1
3589.908		5 d?	3596.454		0000
3590.023	C	0000	3596.534		0000
3590.109	Mn, C	00	3596.651	Co	0
3590.235	Fe, C	1	3596.787		0000
3590.383		0000	3596.894		0000
3590.443		0000	3597.001		0000
3590.509 [2]	C	2 N	3597.189 s	Fe	5 d?
3590.609		2	3597.294		0000
3590.651		2	3597.394		0000Nd?

[1] Beginning of second head of carbon band.

[2] Beginning of first head of carbon band.

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3573.207	Fe	1 N	3579.185		00
3573.320		0000	3579.268		0000 N
3573.417		0000	3579.508		000 N
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3577.705		0000	3584.147		0000
3577.885		0000	3584.237		0000
3578.014	Mn	5	3584.397		0000
3578.138		0000	3584.457		000
3578.240	Co	1	3584.523		0000
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3586.268	Fe	4	3592.508		0000
3586.390		000	3592.619	Fe	1
3586.494		00	3592.745		000
3586.624		0000	3592.819	Fe	3
3586.684	Mn	4	3592.935		0000
3586.890		3	3593.040	Y	0
3587.024		0	3593.158		0000
3587.130	Fe	8	3593.223		0
3587.286	Ti	2	3593.402		000
3587.370	Co	7	3593.481	Fe	3
3587.497		000	3593.636	Cr	9
3587.574	Fe	3	3593.835		000
3587.757	C	0000 N	3593.935		000
3587.899	Fe	5	3594.138		000 N
3588.084	Ni	6	3594.245		000
3588.263	C	000	3594.458		0000
3588.387		0	3594.528		0000
3588.466	C	00	3594.784	Fe	6
3588.563		0000	3595.017	Co	3
3588.675		3	3595.161		0000
3588.763	Fe	4	3595.256	Mn	1
3588.916	C	0000	3595.449	Fe, Ti	2
3589.065	Fe, C	2	3595.554		0000
3589.253	Fe	4	3595.681		0000 N
3589.363	C	0000	3595.824		000
3589.446	C	000	3596.012	Fe	1
3589.601	Fe	2	3596.195	Ti	4
3589.773		5	3596.346	Fe	1
3589.908		5 d?	3596.454		0000
3590.023	C	0000	3596.534		0000
3590.109	Mn, C	00	3596.651	Co	0
3590.235	Fe, C	1	3596.787		0000
3590.383		0000	3596.894		0000
3590.443		0000	3597.001		0000
3590.509 [2]	C	2 N	3597.189 s	Fe	5 d?
3590.609		2	3597.294		0000
3590.651		2	3597.394		0000Nd?

[1] Beginning of second head of carbon band.
[2] Beginning of first head of carbon band.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3621.520		0000 N	3627.763		000
3621.612 s	Fe	6	3627.855		00
3621.740		0000	3627.953	Co	4
3621.864	Fe	2	3628.099		0000 N
3622.007		0000 N	3628.238	Fe	2
3622.147 s	Fe	6	3628.419		000 N
3622.297		0	3628.579		0000 N
3622.407		0000	3628.739		00
3622.577		0000 N	3628.847 s	Y, Mg?	2
3622.694		0000 N	3628.967	La	2
3622.794		000	3629.019		0000
3622.934		0000	3629.146		0000
3623.040		0000	3629.286		0000Nd?
3623.180		0000	3629.492		000 N
3623.234		0000	3629.652		0000 N
3623.362 s	Fe	5	3629.877	Mn	1
3623.460		0000	3630.045	Ni	1
3623.588 s	Fe	2	3630.164		1
3623.650		00	3630.252		0000
3623.750		0000	3630.374		0
3623.925	Mn, Fe	4	3630.492	Fe	4
3624.057		1	3630.618		0000
3624.204		2	3630.718		0000
3624.258	Ca	3	3630.798		0000
3624.447	Fe Co	3	3630.876		4
3624.600		0000 N	3630.918		3
3624.707		0000	3631.124	Ca	2
3624.873	Ni	4	3631.244	Fe	3
3624.979	Ti, Fe	5	3631.404	Co	1
3625.103	Co	1	3631.495	Ti?	0
3625.287	Fe	5	3631.605 s	Fe	15
3625.389		0000	3631.725		0
3625.506		0000 N	3631.850	Co	1
3625.641		1	3631.928		000 N
3625.766		0000 N	3632.098		2
3625.893		000	3632.193	Fe	3
3625.993		0000	3632.312		0
3626.073		0000	3632.438		00
3626.156		0000	3632.585		0000
3626.249	Ti	0	3632.700	Fe	3
3626.327	Fe	1	3632.832		0000
3626.526		0000 N	3632.979	Co, Cr, Zr	1
3626.633		0000 N	3633.123	Fe	4
3626.746		0000	3633.215		2
3626.877		2	3633.277	Y	2
3627.046		0000 N	3633.447		0000 N
3627.201	Fe	2	3633.651	Ti	00 Nd?
3627.309		000	3633.791		000
3627.499		000 N	3633.974	Fe	4
3627.596		000 N	3634.031		1

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3634.144		0000 N	3639.588	Co	2
3634.337		3	3639.663	Pb	1
3634.417		000	3639.833		0000
3634.471	Fe	3	3639.943	Cr	2
3634.551		1	3640.123		0000
3634.611		00	3640.256		0000 N
3634.674		000	3640.403		0000
3634.757	Pd	0000	3640.535 s	Cr-Fe	6
3634.849	Fe-Co	4	3640.783		000
3635.004		0000	3640.903		0000
3635.091	Ni	3	3641.043		0000
3635.164		1	3641.170		1
3635.224		0000	3641.366		0000 N
3635.336	Ti, Fe	2	3641.473	Ti	4
3635.419		000	3641.597	Mn, Cr	1
3635.491		00	3641.784	Ni	1
3635.608 s	Ti, Fe	4	3641.930	Co	0
3635.791		000 N	3641.970	Cr	1
3635.967		00	3642.102	Fe	00
3636.034		0000	3642.285		0000 N
3636.184		0000	3642.419		000 N
3636.305	Fe	3	3642.536		000
3636.377	Fe	2	3642.675		0000
3636.624		1	3642.820	Ti	7
3636.728	Cr	2	3642.912	Sc	2
3636.802	Fe	2	3642.965		3
3636.890	Co	2	3643.109		0000
3637.004		0000	3643.262	Fe	2
3637.139		2	3643.342	Co	1
3637.197	Fe	1	3643.492		0000
3637.397	Fe	1	3643.615		0000
3637.456		0000	3643.764	Fe	4
3637.583		0000	3643.867	Fe?	2
3637.693		00	3643.949		3
3637.876	Fe	0	3644.089		000
3638.011	Fe	4	3644.212		0000 N
3638.113		000	3644.289		0000 N
3638.196		0000	3644.455		0000 N
3638.242		1	3644.555	Ti, Ca	5
3638.306		1	3644.729		0
3638.383		1	3644.833	Ti, Fe	1
3638.442 s	Fe	3	3644.932	Fe	3
3638.610		0000	3645.117		0
3638.743		0000	3645.221	Fe	2
3638.910		0000	3645.325		0000
3639.043		000	3645.429		3
3639.168	V	0	3645.475	Sc?,-	3
3639.270		0000	3645.552	La	00
3639.423		1	3645.636	Fe	3
3639.470		0000	3645.765		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3645.967	Fe	4	3652.691 s	Co	3
3646.074		0000	3652.820		0000Nd?
3646.128		0000	3653.023		0000
3646.236		00	3653.160		0000
3646.335	Ti	1	3653.260		0000
3646.491		0000 Nd?	3653.340		0000
3646.643		000	3653.492		1
3646.757		2	3653.637 s	Ti	5
3646.948		000 N	3653.799		0000
3646.976		00 N	3653.900	Fe	2
3647.128		2	3654.052	Cr	2
3647.234	Co	0	3654.119	Fe	2
3647.394		0000 Nd?	3654.266		0000 N
3647.561	Fe	4	3654.392		0000 N
3647.701		0	3654.526		0000
3647.808		0	3654.586	Co	00
3647.988 s	Fe	12	3654.738	Ti	2
3648.221	Co	0 N	3654.813	Fe	1
3648.367		0	3654.999	Hg?	0000
3648.461		00 N	3655.143	Fe	2
3648.669	Cr	0	3655.199		0000
3648.778		0000	3655.359		00
3648.898		0000	3655.495		1
3648.954		000	3655.609	Fe	3
3649.137	Cr	1	3655.719		0000
3649.234		0000	3655.801		3
3649.324		0000	3655.990		0000
3649.438	Fe	4	3656.080		0000 N
3649.476	Co	3	3656.217		0000
3649.654	Fe, La	5	3656.358	Fe	3
3649.838		00	3656.404	Cr	2
3649.977	Co	1	3656.496		1
3650.178	Fe	4	3656.687		000
3650.423	Fe	5	3656.844		0000Nd?
3650.507		0000	3656.997		0000 N
3650.681		2	3657.104	Co	0
3650.860		0000 N	3657.275	Fe	2
3651.027		0000 N	3657.437		0000 N
3651.179		00	3657.562	Fe	1
3651.247	Fe,-	6	3657.710		0000 N
3651.337		00	3657.850	Fe	1 N
3651.400		0000	3657.957		0000
3651.493		0000 N	3658.044	Co, Fe, Mn	3
3651.614	Fe	7	3658.163		1
3651.794		1	3658.238	Ti	1
3651.940	,-Sc	4	3658.306		0000
3652.061		1	3658.413		0000 N
3652.247		0000	3658.529		000 N
3652.400		00	3658.689 s	Mn-Fe	1
3652.537		0000	3658.783		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3659.003		0000 N	3664.760	Y	2
3659.109		0000 N	3664.838	Fe	2
3659.263		0000 N	3664.965		000 N
3659.373		0000 N	3665.082		000 N
3659.449		0000	3665.165		00 N
3659.663	Fe	5	3665.325		0000
3659.759		0000	3665.441		0000
3659.901	Fe-Ti	5	3665.574		0000
3660.016		0000	3665.731		0000
3660.109		0000 N	3665.861		00
3660.349		00	3665.987		0000
3660.467	Fe	2	3666.134	Ni	0
3660.549	Mn	1	3666.201	Fe	1
3660.663		0000	3666.301		0000
3660.774	Ti	2	3666.387	Fe	3
3660.916		2	3666.421		2
3661.059		0000 N	3666.504		0000
3661.176		000 N	3666.676		1
3661.289		0000	3666.781	Cr	00
3691.396		0000	3666.907	Fe	3
3661.506	Fe	3	3666.986		000
3661.675		0000	3667.068	Fe	3 Nd?
3661.775		0000	3667.234		0000Nd?
3661.875		0000	3667.397 s	Fe	4
3661.975		0000	3667.561		0000 N
3662.096	Ni	3	3667.741		0000 N
3662.195		0000	3667.887		000
3662.308	Co	1	3668.014		0000
3662.378	Ti	5	3668.133	Fe	4
3662.502		0000	3668.354	Fe, Ni	3
3662.608		0000	3668.491		0000 N
3662.762		0000 N	3668.597	Zr	00
3662.875		000	3668.634		00
3662.978	Fe, Cr	4	3668.796		00
3663.035		0000	3668.907		0000 N
3663.155		0000 N	3669.028	Fe	0
3663.208		0000 N	3669.106	Ti	1
3663.346	Cr	1	3669.292	Fe	2
3663.402	Fe	3	3669.381	Ni	4
3663.541		3	3669.543		00 N
3663.596	Fe	3	3669.666	Fe	4
3663.735		0000 N	3669.823		1
3663.835		0000 N	3669.976	Mn	0000 N
3663.968		0000 Nd?	3670.168	Co	3
3664.104	Fe	2	3670.240	Fe	2
3664.234	Ni	5 d?	3670.356		0000
3664.348		000	3670.446		0000
3664.375		0000	3670.566	Ni	5
3664.548		0000 N	3670.678	Mn	0 N
3664.677	Fe	3	3670.786		0000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3670.860		00 N	3677.231		0000
3670.953	Fe	4	3677.308		0000
3671.046		0000 N	3677.457	Fe	4
3671.226		0000 N	3677.598	Fe	3
3671.358		000	3677.650		3
3671.412	Zr	0	3677.764	Fe	5
3671.506		0000	3677.831		3
3671.660	Fe, Pb	0	3677.991		3
3671.819	Ti	3	3678.045		2
3671.993		0000	3678.236		000 N
3672.083		0000	3678.370		1 Nd?
3672.260		000	3678.491		0000
3672.452		0000	3678.591		0000
3672.601		000	3678.718		0000
3672.742		0000	3678.864		0000
3672.851	Fe	3	3679.002	Fe	4
3672.939		0000	3679.139	Fe	2
3673.049		0000	3679.248		000 N
3673.182		0000	3679.488	Fe	1
3673.226	Fe	3	3679.575		0000
3673.362		0 N	3679.675	Fe	1
3673.562		000	3679.821		2
3673.679		0000	3679.947		0 N
3673.819		00	3680.069 s	Fe	9
3673.909		0000	3680.137		0 N
3674.025	Fe	2	3680.261		0 N
3674.198	Fe	4	3680.347		0000 N
3674.287	Ni	4	3680.525		2
3674.452		0000	3680.641		0000
3674.550	Fe	2	3680.801		3
3674.699		0000	3680.937	Fe	4
3674.865	Zr	1	3681.081		3
3674.909	Fe	2	3681.254		0000
3675.059		0000	3681.368	Fe	2
3675.135		0000	3681.501		0000
3675.255		0000 N	3681.604		0000
3675.430		1	3681.787	Fe	3
3675.585		00	3682.021	Fe	0
3675.692		0000	3682.161	Mn	000
3675.825	V	1	3682.310		2
3675.902		0	3682.382	Fe	5
3676.018		0000	3682.661		00 N
3676.112		000	3682.807		0 N
3676.291		0000	3683.021		000 N
3676.457	Fe, Cr	6	3683.182	Co	3
3676.698	Co	2	3683.229	Fe-V	4
3676.836		0000	3683.514		0000
3676.950		0000	3683.617	Pb?	0000
3677.016	Fe	3	3683.761		2
3677.098		0000	3683.893		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3684.020		0000	3690.019	Fe	1
3684.106		0000	3690.053	Ti	2
3684.258 s	Fe	7 d?	3690.205		0000
3684.360		0000	3690.420	V-Pd	1
3684.460		0000 N	3690.599	Fe	2
3684.600	Co-	000 N	3690.732		0000
3684.680	Mn	000 N	3690.870	Co-Fe	4
3684.858		0000 N	3690.999		0000
3685.000		0000 N	3691.112		0000 N
3685.140		000 N	3691.315		000 N
3685.339	Ti	10 d?	3691.452	Fe, Mn	2
3685.665	Mn, Cr	1	3691.534		0000
3685.810		0000	3691.674		0000
3685.913		0000	3691.824		0000
3686.026		0000	3691.954		0000
3686.141	Ti-Fe	6	3692.101		0000
3686.246		0000	3692.251		0000
3686.326		0000	3692.364	V	1
3686.399	Fe, V	3	3692.498		0000
3686.520		0000	3692.578		0000
3686.611		0000	3692.708		0000
3686.813		000	3692.790	Fe	2
3686.926	Cr	1	3692.954	Mn	000 N
3687.010		000	3693.024		0000
3687.083		0000	3693.170	Fe	3
3687.234	Fe	3	3693.258	Co	1
3687.380	Cr	1	3693.384		0000
3687.473		1	3693.504		000
3687.610 s	Fe	6	3693.616	Co	1
3687.690	Cr?	000	3693.804	Mn	0
3687.800	Fe	4	3693.921		0
3687.899		0000	3694.077	Ni	2
3688.005		0000	3694.164	Fe	4
3688.125		0000	3694.344		3
3688.210	V	1	3694.576	La	1
3688.312		2	3694.791		0000
3688.425		0000	3694.954		000
3688.558	Ni	4	3695.041		0000
3688.617	Fe	3	3695.194 s	Fe	5
3688.819		0000	3695.344		0000 N
3688.943		2	3695.479	V	0
3689.013	Fe	1	3695.658	Fe, Mn	1
3689.141		1	3695.789		2
3689.219	Fe	1	3696.006	Fe, V	1
3689.345		0000 N	3696.175	Fe	0
3689.459		000	3696.290		0000 N
3689.513		3	3696.433		0
3689.614	Fe	6	3696.520		0
3689.769		0000	3696.660		000
3689.839		0000	3696.707	Mn	0

Wave-length	Substance	Intensity and Character
3696.800	Mn	0
3696.890		000
3696.949	Ti	00
3697.047	Fe, Ni	1
3697.243		000 N
3697.397		000 N
3697.567	Fe	5
3697.677		3
3697.883		000
3698.007		000
3698.153		1 N
3698.303	Ti, Zr	2
3698.463		000 N
3698.613		00 N
3698.744	Fe	4
3698.830		00
3698.940		000
3699.023		000
3699.153	Co	00
3699.283	Fe	3
3699.413		000 N
3699.533		000
3699.710		000
3699.877		000
3699.962		1
3700.062		000
3700.182	Ti	00
3700.269		00
3700.406		000
3700.479		1
3700.596		000
3700.737		1
3700.876		000
3700.942		000
3701.052		000
3701.132		000
3701.234	Fe	8
3701.409		000
3701.512		000
3701.672		000
3701.749		000
3701.866	Mn	0
3702.006		000 Nd?
3702.170	Fe	4
3702.382	Co	2
3702.409	Ti	2
3702.629	Fe	4
3702.782		000 Nd?
3702.962		000 Nd?
3703.099		000 N
3703.242		000
3703.369		000 N
3703.586		000
3703.683	Fe-V	4
3703.729		3
3703.834	Fe	3
3703.962	Fe	2
3704.176		2
3704.221	Co	3
3704.341		000
3704.435		00
3704.485	Ti	0
3704.603	Fe	4
3704.842	V	1
3704.935		000
3705.051		000
3705.171	V	0
3705.251		000
3705.401		00 N
3705.561		00 N
3705.708 s	Fe	9
3705.849		2
3705.968		000 N
3706.075		00
3706.175	Mn-	6 d?
3706.363	Ti	3
3706.475		000
3706.621		000
3706.701		000 N
3706.835		000 N
3707.021		000
3707.186 s	Fe	5
3707.315		000
3707.468		2 N
3707.600	Co	2
3707.702	Ti	2
3707.815		000
3707.959	Fe?	5 d?
3708.068	Fe	5
3708.224		00
3708.327		000
3708.454		000 N
3708.574		000 N
3708.741		1
3708.834	Ti, V	000
3708.964	Co	1
3709.170		1
3709.290		00 N
3709.389 s	Fe	8
3709.540		0 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
3709.675	Fe	1	3716.293		0000 N
3709.808	Fe	1	3716.517		00
3709.967		000	3716.591 s	Fe	7
3710.094	Ti	0	3716.677		00
3710.214		00	3716.838		0000
3710.304		000	3716.905		0000
3710.431 s	Y	3	3717.084		000 N
3710.587		00 N	3717.211		000
3710.777		00 N	3717.326		00
3710.880		000	3717.410		0000
3711.020		000 N	3717.539	Ti	2
3711.254		000	3717.695		0000 N
3711.364	Fe	4	3717.812		0000
3711.440		000	3717.872		0000
3711.552	Fe	3	3717.975		0
3711.674		000	3718.093		000 N
3711.804		000 N	3718.291		0 N
3711.923		000 N	3718.367		000
3712.079		0	3718.460		000
3712.229		00	3718.554	Fe	4
3712.319	Co	00	3718.665		0000
3712.443		000	3718.754		000 N
3712.539		000	3718.845		0000
3712.666		000	3718.978		0000
3712.856		000	3719.070	Mn, Pd	1
3712.906		000	3719.168		0000
3713.037		{ 2	3719.332		0000 N
3713.087	Cr	{ 3	3719.405		0000
3713.239		000	3719.545		0000 N
3713.346		000	3719.598		000 N
3713.479	Ni	00	3719.683		000 N
3713.693		000 N	3719.796 [1]		0 N
3713.853	Ti	0	3719.905		0000 N
3713.973		000	3720.084 s	Fe	40
3714.109		000 N	3720.184		0000
3714.296		000 N	3720.305		0 N
3714.359		000 N	3720.400		000 N
3714.546		000	3720.544		00 Nd?
3714.706		000	3720.704		0000Nd?
3714.813		000	3720.832		0000 N
3714.926	Zr	0	3720.930		0000
3715.069		000	3721.048		0000
3715.179		000	3721.171		0000
3715.319		2	3721.212		0000
3715.536		0000	3721.326		2
3715.615	Mn?	4	3721.418	Fe	3
3715.853		0000 N	3721.540	Fe	2
3715.938		0000	3721.647	Fe	2
3716.054	Fe	3	3721.779	Ti	4 d?
3716.172		0000			

[1] This line is variable, though not an atmospheric line.

ON THE OCCURRENCE OF VANADIUM IN SCANDINAVIAN RUTILE.[1]

By B. Hasselberg.

The problem of assigning to each chemical element its definitive emission spectrum has been carried perceptibly nearer to its solution, since the necessary basis was established by the classical work of Rowland. Yet when the attempt is made to extend it to the fainter radiations, as well as to the principal lines of the spectrum, the question becomes complicated to such an extent that an exhaustive solution seems to be well nigh hopeless. It is therefore necessary, in this department of spectroscopic research, to be contented with a series of approximations; and no very great surprise need be felt if in a single case, where every effort has been made to eliminate such impurities as were most likely to occur, other impurities have been encountered, the presence of which there was in the beginning scarcely any reason to suspect. The present lines are devoted to a preliminary account of such a case as the above.

For producing the spectrum of titanium in the electric arc I have used titanic acid in the form of rutile with materially better success than when commercial titanium was employed, since the metal burns much too quickly when introduced into the arc, and is scattered in all directions. This rutile, which was kindly obtained for me by Baron Nordenskiöld, comes from Krageröe in Norway. As in other kinds of rutile, its chief component is titanic acid, since, according to analysis of a number of varieties of this mineral,[2] the only other constituent to be expected is oxide of iron in the proportion of from 1 to 2 per cent. After eliminating the iron lines which are thus caused to appear on the spectrograms, as well as other metallic lines, whose presence was revealed by comparison with my own investigations

[1] "Ueber das Vorkommen des Vanads in den skandinavischen Rutilarten." *Bihang till Svenska vetensk. Akad. Handl.* 22, Afd. 1, No. 7.

[2] Dana's *Descriptive Mineralogy*, 5th edition, 160, New York, 1883.

of metallic spectra and with those of Kayser and Runge, I considered myself justified in ascribing the remaining lines to pure titanium, or at least in considering that only a few isolated cases remained in which contamination by a foreign metal might subsequently be proved. The continuation of my spectroscopic researches has shown, however, that this does not entirely hold good, since among the fainter and faintest lines of my titanium spectrum there are several that doubtless belong to *vanadium*. Having obtained through Baron Nordenskiöld a large piece of this metal, which was made by Moissan of Paris in the electric furnace, I recently began a re-examination of the spectrum, and discovered several strong groups of lines in the blue and violet parts, the approximate wave-lengths of which agreed very closely with those of faint lines previously measured in the spectrum of titanium. In order to obtain a final decision on this point, the parts of the spectrum in question of vanadium and rutile were photographed in juxtaposition on the same plate, in the usual manner, and compared line by line. The result of this investigation of approximate coincidences is shown in the accompanying table.

In the first two columns of this table are given the approximate wave-lengths and intensities of vanadium lines, in the region $\lambda\,403-\lambda\,405$, for which corresponding fine lines occur on the comparison plates of the spectrum of Norwegian rutile. These lines are given, with their intensities, in the two following columns, the wave-lengths being those of my former catalogue of titanium lines. As will be seen, the coincidences are almost all exact; and hence the corresponding faint titanium lines are to be removed from the titanium spectrum as properly belonging to vanadium.

I must confess that I have been greatly surprised by this result. It will be granted, I think, that there were no possible reasons for suspecting it in advance, since vanadium has never been found in any of the numerous varieties of rutile hitherto known. Under these circumstances it seemed to me desirable to subject another kind of rutile to the same test. For this pur-

Vanadium λ	i	Rutile I λ	i	Rutile II λ	i	Remarks
4033.03	1.2	——				Also a weak line in Ti.
90.70	3	90.73	1			
92.87	3	92.83	1.2			
95.60	3	95.65	1			Coincident, belong to Va. All the rutile lines are weaker on the comparison plate than here represented.
4100.00	3.4	4099.94	1.2			
05.30	3	05.31	1.2			
09.95	3.4	09.92	1.2			
12.00	4	11.91	2.3			
15 30	3.4	15.32	2			
16.65	3	16.64	1.2			
23.65	3	23.68	2.3			Divided. λ Ti > λ Va.
28.25	3.4	28.20	2			Coinc. Belongs to Va.
31.35	1	31.38	1.2			Divided. λ Ti < λ Va.
34.60	3.4	34.60	1.2			Coinc. Belongs to Va.
59.87	2.3	59.79	2.3			Divided. λ Ti < λ Va.
69.45	1.2	69.46	2			Clearly divided. λ Ti > λ Va.
83.45		83.45	1.2			Probably divided. λ Ti > λ Va.
4227.95	2	27.80	2			Widely separated.
68.85	3	——	1	——	1	
71.80	3	——	1	——	1	
4330.15	3	——	1−	——	1+	
33.00	3	——	1−	——	1+	All these lines occur on the rutile photographs with the observed intensities. The blanks in the columns 3 and 5 of wave-lengths indicate that these lines do not occur in my catalogue of the titanium lines. On the plates here investigated they occur with the given intensities.
41.15	3	——	1+	——	1 2	
53.05	3.4	53.01	1	53.01	1.2	
79.45	4.5	79.40	2	79.40	3	
84.90	4.5	84.85	2	84.85	2.3	
90.15	4.5	90.11	2	90.15	2+	
95.40	4	——	2	——	2	
4400.75	4	00.74	1.2	00.74	2	
06.85	4.5	——	1.2	——	2	
07.90	4.5	07.85	1.2	07.85	2+	
08.40	4	08.39	1.2	08.39	2+	
08.65	4.5	08.70	1.2	08.70	2+	
16.65	3	16.70	2	16.70	2	Clearly divided. λ Ti > λ Va.
41.90	3.4	41.86	1.2	41.86		Perhaps. λ Ti > λ Va.
44.40	3.4	44.41	3	44.41		Probably divided. λ Ti > λ Va.

pose Swedish rutile from Käringbricka in Westmanland was chosen, one reason among others for doing so being that the results of Ekeberg,[1] according to which this particular kind also contains chromium, could be tested at the same time. A double exposure to the spectrum of this mineral and of vanadium in the region λ 425–λ 445 having been made, the same series of coincidences was found as in the case of the Norwegian rutile (see the fifth and sixth columns of the table), and hence at the same

[1] *Sevenska vetensk. Akad. Handl.* 46, 1893. Dana's *Mineralogy.*

time the fact was demonstrated that Swedish rutile also contains vanadium.

If, further, the observed intensities of the vanadium lines which occur in the photographic spectra of the two kinds of rutile are compared, it will be seen that the intensities for rutile II, obtained at Käringbricka, are greater throughout the spectrum than those for rutile I. Since this fact appears to indicate that Swedish rutile contains a greater amount of vanadium than Norwegian, it was of interest to test the relation of the two varieties in this respect by a special experiment, in which the exposure and development were exactly the same. With this object two exposures in the upper region of the spectrum were made on the same plate, using for each a different half of the slit, with electrodes which in one case were made of Norwegian and in the other case of Swedish rutile. The exposure was in each case 1.5 minutes. The developed plate showed the titanium lines with identically the same intensity in both spectra, while the vanadium lines were considerably stronger in the spectrum of the Swedish rutile. In order that this fact may be clearly brought out, I have made the accompanying photographic copy of a drawing,[1] in which the appearance of the negative under the microscope of the measuring engine is represented with all possible exactness. It will be seen that vanadium lines of the Norwegian rutile have a distinctly lower intensity, so that in fact some of the weakest of them fail to appear.

From what has been given above, I believe that it may be regarded as proved that both kinds of rutile contain vanadium, the Norwegian as well as the Swedish, but that the Swedish variety contains a considerably greater amount of this metal than the other. Whether this amount of vanadium is great enough to be recognized or quantitatively determined by ordinary chemical analysis is a question for the solution of which the above experiments afford no data, or at least only such as are highly uncertain, for we have as yet no trustworthy information as to the sensitiveness of the spectral reactions of the elements.

[1] Not reproduced in this JOURNAL.

On the plates which contain the spectra of the two kinds of rutile, the correspondence of lines (leaving out of consideration the difference of intensity of the vanadium lines already mentioned) is complete, with one exception. This exception is found in three quite strong lines which occur in the spectrum of the Swedish rutile, but of which there is scarcely a trace in the other variety. By referring their positions to neighboring titanium lines I obtained for these lines the following wave-lengths:

$$\lambda = 4254.50$$
$$74.90$$
$$89.90$$

while the strongest lines in the whole chromium spectrum have, according to my earlier measures, the wave-lengths

$$\lambda = 4254.49$$
$$74.91$$
$$89.87$$

The lines therefore belong to chromium, the presence of which is thereby demonstrated, and this result is in agreement with the analysis of Ekeberg.

A NEW FORMULA FOR THE WAVE-LENGTHS OF SPECTRAL LINES.[1]

By J. J. BALMER.

SINCE the wave-lengths of lines in the simple spectrum of hydrogen can be represented with surprising accuracy by a simple formula, it was to be expected that a formula could also be found for the spark spectra of other elements, which would be capable of representing their wave-lengths in a satisfactory manner. Professor E. Hagenbach-Bischoff has been kind enough to send me information from time to time concerning the researches and experiments that have been made in this direction. It is first to be noted, that the spectrum of any metal, as for example lithium or thallium, does not exhibit merely a single series of regularly ordered lines, but several such series, which are in general superposed, and thereby so confused that the lines of the different series appear to be jumbled together without law or order. The circumstance that the lines belonging to any one series have a certain characteristic appearance, so that the lines of one series may be sharp, those of another diffuse on the side toward the red, and those of still another diffuse toward the opposite side, makes it possible to unravel the complex of series; and when this is done it is found that every series approaches with continually narrowing line-intervals a definite and characteristic limit which lies toward the side of shorter wave-lengths. In approaching the limit the lines also become gradually fainter and more indistinct, and thus the difficulties of exact measurements are increased. Professors Kayser and Runge[2] of Hannover, who have investigated the spectra of a great number of elements with extraordinary accuracy and astonishing diligence, and have measured the wave-lengths of the lines in their series, have

[1] "Eine neue Formel für Spectralwellen." *Verhand. d. Naturforsch. Gesell. Basel, Band* 11, *Heft* 3.

[2] "Ueber die Spectren der Elemente." Berlin, 1888 *et seq.*

shown that the oscillation-frequencies, which are inversely proportional to these wave-lengths (or instead of them the reciprocals of the wave-lengths), can be represented by an algebraic series with descending powers of n^2, and that the first three terms of such a series suffice to represent the line series with a very close approximation to the numerical values deduced from observation; the longest and shortest waves perhaps excepted. For determining the three constants in this approximate formula only three oscillation-frequencies determined by measurement are required, for which the numbers n expressing the order must also be known. (For the longest possible wave this number always $= 3$.) The formula itself is, when the reciprocal of the wave-length λ_n is represented by τ_n,

$$\tau_n = A - \frac{B}{n^2} - \frac{C}{n^4}.$$

For representing the longest or at most the two longest waves, the above formula of three terms is not sufficiently accurate, and for this purpose it would be necessary to determine a fourth or fifth constant; but the values of such additional constants would be highly uncertain, since with our present means it is not possible to measure the wave-lengths with sufficient accuracy. (The accuracy at present attainable is about $\frac{1}{100000}$ of a wave-length.) The very simple formula of Kayser and Runge is of the highest value for testing and checking the results of measurement on account of the ease with which the constants can be determined, as it requires merely the solution of an equation of the first degree with three unknown quantities, and it has also served in part to determine the components of the different series. But it cannot be regarded as the real expression of the natural law governing the phenomena of the spectrum. Although the formula as used in practice has only three terms, it is nevertheless to be regarded as a finite or closed function whose denominator contains two terms, developed into an infinite series; and only after we should have succeeded in ascertaining what this closed function is, should we possess the basis for a correct explanation of spectral phenomena. It is

further to be noted that the three constants in the abridged formula of Kayser and Runge do not stand in any demonstrable relation to one another, although the second constant, in any one case, differs by only a few per cent. from a constant mean value.

I have lately made many experiments, which were often abandoned and again renewed, having for their object the discovery of such a closed expression, and in this work the friendly interest of Professor Hagenbach was a constant incentive to effort when there seemed to be no hope of success.

A first short opportunity for examining Messrs. Kayser and Runge's results led me to experiment upon the first line-series of two metals, lithium and thallium, in order to ascertain the most certain method of arriving at a solution of the problem. I observed as a consequence of performing the computations connected with this work, that if the differences of a series of wave-lengths are formed, the quotients obtained by dividing each of two adjoining differences by the next succeeding difference, form a series which answers the requirements almost exactly, and which has the extremely simple form $(n+2):(n-1)$. It is only in the case of the greatest wave-lengths that the error becomes fairly considerable. The law of the series of hydrogen lines is quite accurately represented by the formula:

$$Q_n = \frac{(2n-1)\cdot(n-1)\cdot(n+3)}{(2n+1)\cdot(n+1)\cdot(n-3)},$$

in which the lines λ_{n-1}, λ_n, λ_{n+1} are used in forming the differences. Now, on comparing the corresponding quotients for thallium with those for hydrogen, the striking fact appears, that the two corresponding series do not cover one another, but that one of them appears to be intermittently inserted between the figures of the other. This fact leads to the conjecture that in the true closed formula of the spectrum the integral number n is increased by the addition of some fraction, which is, perhaps, constant. Thus I arrived at the conclusion that the mixed number $n+c$ should be introduced into the formula instead of the integer n, in order to obtain the formula for other elements, and in this way arrived at the expression:

OBSERVED AND COMPUTED WAVE-LENGTHS OF HELIUM LINES.

	Series I α and β			Series II			Series III α and β		
	α computed from lines 1, 3, 9. β computed from lines 1, 3, 7.			Computed from lines 1, 4, 7.			α computed from lines 1, 3, 5 β computed from lines 1, 3, 5.		
	α		β				α		β
	$a=$ 3420.96		3420.99	$a=$3120.797			$a=$2599.342		2599.317
	$b=$3.758942		3.756648	$b=$3.427311			$b=$2.871562		2.869745
	$c=$1.999392		1.998615	$c=$2.011946			$c=$1.942689		1.941889
n	O.	C.	Diff.	O.	C.	Diff.	O.	C.	Diff.
1	5876.206	5876.206	0.	5015.73	5015.73	0.	3888.97	3888.97	0.
	5875.883	5875.880	−0.03				3888.76	3888.76	0.
2	4471.85	4471.870	+0.02	3965.08	3965.031	−0.049	3187.98	3188.313	+0.333
	4471.66	4471.610	−0.05	3964.84		+0.191	3187.83	3188.115	+0.285
3	4026.52	4026.523	+0.003	3613.89	3613.872	−0.018	2945.57	2945.57	0.
	4026.35	4026.350	0.	3613.78		+0.092	2945.42	2945.42	0.
4	3819.89	3819.891	+0.001	3447.73	3447.73	0.	2829.32	2829.406	+0.086
	3819.75	3818.770	+0.02				2829.16	2829.286	+0.126
5	3705.29	3705.247	−0.043	3354.7	3354.635	−0.065	2764.01	2764.01	0.
	3705.15	3705.16	+0.01				2763.91	2763.91	0.
6	3634.52	3634.451	−0.069	3296.9	3296.817	−0.083	2723.3	2723.302	+0.002
	3634.39	3634.39	0.						
7	3587.54	3587.461	−0.079	3258.3	3258.300	0.	2696.5	2696.153	−0.347
	3587.42	3587.42	0.						
8	3554.5	3554.59	+0.09	3231.3	3231.276	−0.024	2677.1	2677.101	+0.001
		3554.56	+0.06						
9	3530.6	3530.65	+0.05	3213.4	3211.565	−1.835			
		3530.63	+0.03						
10	3512.6	3512.66	+0.06						
		3512.65	+0.05						
11	3498.7	3498.78	+0.08						
		3498.78	+0.08						
12	3487.8	3487.85	+0.05						
		3487.85	+0.05						
13	3479.2	3479.09	+0.11						
		3479.09	+0.11						

$$\lambda_n = a\frac{(n+c)^2}{(n+c)^2-b}\,;\ \text{or,}\ \tau_n = A - \frac{B}{(n+c)^2}\,.$$

I first tested this formula on the series I of lithium. Previous experiments had shown that for this element the constant a is about 2300 tenth-meters. With the value 4 for b, the value determined for c was 0.72332, and with these constants the computed wave-length of the second line at λ2741.39 was 2802, or about 60 units too great. For $a=2300$ and $b=3$ (instead of 4), and with the corresponding value $c=0.2245$ deduced with their

OBSERVED AND COMPUTED WAVE-LENGTHS OF HELIUM LINES.

	Series IV.			Series V α and β			Series VI.		
	Computed from lines 2, 3, 4. a=3678.613 b=4.042545 c=2.000229			α computed from lines 2, 5, 8. β computed from lines 2, 5, 8. α: a=3421.275, b=3.746843, c=1.696996 β: 3421.109, 3.747853, 1.697826			Computed from lines 1, 4, 7. a=3679.022 b=4.027016 c=1.852937		
n	O.	C.	Diff.	O.	C.	Diff.	O.	C.	Diff.
1	6678.1	6677.5	−0.6	7065.77* 7065.51*	7055.86 7054.83	−9.91 −10.68	7281.8	7281.81	+0.01
2	4922.08	4922.08	0.	4713.39 4713.17	4713.39 4713.17	0. 0.	5047.82	5048.529	+0.709
3	4388.11	4388.11	0.	4121.15 4120.98	4121.196 4121.047	+0.046 +0.067	4437.73	4437.859	+0.129
4	4143.91	4143.91	0.	3867.77 3867.61	3867.790 3867.652	+0.02 +0.042	4169.12	4169.12	
5				3733.15 3733.01	3733.15 3733.01	0. 0.	4024.14	4024.083	−0.057
6				3652.29 3652.15	3652.261 3652.118	−0.029 −0.032	3936.1	3936.051	−0.049
7				3599.59 3599.45	3599.588 3599.443	−0.002 −0.007	3878.3	3878.3	0.
8				3563.26 3563.11	3563.26 3563.11	0. 0.	3838.2	3838.237	+0.037
9				3536.9	3536.946	+0.046	3808.3	3809.256	+0.956
10				3517.5	3517.452	−0.048			
11				3502.5	3502.530	+0.03			
12				3490.8	3490.839	+0.039			
13				3481.5	3481.514	+0.014			

*Phot. (sic). This line was measured optically. *Ap. J.*, 3, 7. Eds.

aid, the computed wave-length of the second line was 2764.76 or still too great by 23.37 units. A third trial with $b = 2.5$ made $c = -0.05646$ and the second wave-length 2740.56, thus only 0.83 units too small. The computation when extended to the following lines, with the constants last determined, gave results which in the average deviated by only about one-fourth of a unit from the measured wave-lengths. Since only round numbers were used for the first and second constants in this first trial of the new formula, I was greatly surprised at the close agreement of the result, and the

conviction fastened itself upon me that this formula was an adequate expression of a physical truth.

Professor Albert Riggenbach remarked to me, on the occasion of an incidental meeting, that Professors Runge and Paschen had published extremely accurate measures of the lines of helium,—an element which was first discovered in the chromosphere and in some of the Orion stars, but which had not been found in terrestrial substances until very lately, when it was found to exist as clèveite gas in certain minerals,—and he suggested that these measurements would in all probability be very suitable for testing the closed formula. The next day he sent me the figures for the three double series and the three single series of helium lines, according to the communication of Runge and Paschen,[1] and an account of the lines in clèveite gas ascribed by Lockyer to helium, together with the complete general solution of the equation of the third degree with three unknown quantities which is implied in the formula. I here desire to extend my best thanks to Professor Riggenbach for his kind assistance, hints, and communication of facts. The figures which he sent me have been used in my computations, and the results which I have found are exhibited in the tables given above. In the double series, I, III and V, Runge and Paschen have not represented the shortest pairs as divided, no doubt because these pairs are too close and too faint for exact observation. The numbers given for them have therefore one decimal place less than the double lines of the series.

In computing the constants the choice of the lines on which the computation is based has a very great influence on the result, particularly in the case of the longest waves. If, on account of small errors of observation, the adopted values of the wave-lengths differ even very slightly from the true values, the computation of the constants is considerably affected, and this influence is most felt in the greatest wave-lengths with smallest values of n,—not so much through the influence of the con-

[1] *Mathem. u. Naturw. Mittheilungen d. K. preuss. Akad. Wiss.*, Berlin, 323, 377. 1895.

stants a and b as through that of c. When therefore the computed values obtained with the formula are found to deviate here and there from the results of observation, in the case of the longest waves of a series, this fact may be ascribed to the great difficulty of determining the constants, rather than to deficiencies of the formula. It is presumable that in series where observation and computation are at variance in the greatest wave-lengths, complete agreement could be brought about by a suitable change in the constants.

Testimony in favor of the closed new formula is found in its simplicity, which is only equaled by that of the accepted hydrogen formula, and further in its intimate relation with the latter, which is only a special form obtained from the new formula by placing $b=4$ and $c=0$. Still another advantage of the new formula seems to lie in this, that it is now a matter of indifference what integral value is given to n, so long as the lines of a series, and therefore the values of n, progress uninterruptedly; for by as much as n is taken greater or smaller, compensation to that amount is effected by the smaller or greater value of c.

With regard to the meaning of the constants, that of a is quite plain; it indicates the limiting wave-length in which the series of lines terminates. The constant c, on the other hand, indicates the displacement by which the integral values of n must be increased or diminished; a fraction which is constant for one and the same series. The least intelligible significance is that which attaches to the constant b, by which the square of $n+c$ in the denominator is diminished. This constant seems to have the character of a square quantity; for if the constant b in the typical hydrogen formula is diminished from 4 to 1, only the wave-lengths of the originally even values of n remain, and the uneven wave-lengths disappear, so that the curve of wave-lengths is reduced one-half, a change which is repeated in a corresponding manner when other quadratic values are given to b.

The constant b has a quite remarkable relation to the con-

stant a. If for any series of lines a is divided by b, a number is obtained which is equal to within about ½ per cent. to the corresponding quotient for the simple series of hydrogen. The latter quotient is $3645.6:4=911.4$. The corresponding quotient for the helium series I α and β, II and IV, is a little more than 910, and therefore about 0.1 per cent. less than for hydrogen; for series III α and β it is over 905; for series V α and β, and series VI it is nearly 913. For the lithium (single) series I a computation based on the lines 1, 4 and 7, gives for the values of the constants, $a=2299.401$, $b=2.514417$; if lines, 1, 3 and 5, are taken the values are $a=2298.643$, $b=2.536159$. The quotient of the first pair of constants is 914.48, that of the second only 906.20. The mean of the two is 910.34. As I have already remarked it is possible that such discrepancies in the values arise from the unavoidable minute errors of observation, so that a definite judgment as to the incorrectness of the formula should not be based on them. These remarkable approximations to a constant mean value do not at any rate exclude the possibility that we are here dealing with relations that are founded on fact, and that offer to us, like so many others that occur in nature, enigmas to attempt the solution of which there is always an irresistible charm.

ADDENDUM.

Through the kindness of Professor Hagenbach, who lent me the memoir of Messrs. Kayser and Runge for the purpose of more detailed study, I have had the opportunity of becoming acquainted not only with their own results, but with their highly interesting account of a formula proposed several years ago by the Swedish savant Rydberg.[1] The closed formula above given agrees almost perfectly with Rydberg's formula, the only difference being that the constant B $\left(=\frac{b}{a}\text{ of the former}\right)$, instead of having a particular value for each element, is assumed by Rydberg to have a value which is the same for all the elements,

[1] "Spectren der Elemente," 4 Heft, Nachtrag, 61.

(109721.6, or the reciprocal of 911.4 of hydrogen), and therefore equal to the corresponding constant of the hydrogen formula. It may be conjectured that Rydberg has chosen this value for the basis of his formula, because it represents the mean of the corresponding constants for all the other elements, and because this assumption greatly simplifies the computation of the two remaining constants;—for a direct determination of all three constants from three measured wave-lengths requires the some what tedious solution of an equation of the third degree.

Messrs. Kayser and Runge have shown that the original formula of Rydberg leads to less satisfactory results than their abridged series; nevertheless Rydberg ascribes to his own formula greater pretensions to correctness.

Kayser and Runge have further shown that even a modification of Rydberg's formula obtained by giving special values to B in his equation

$$\tau_n = A - B\,(n + c)^{-2}$$

furnishes no better results than three terms of their series of powers. But since Kayser and Runge have not described the manner in which they determined the value of the constant B, it may be assumed as probable that they have used the values of B deduced from their own formula as a basis for this modification. By this process, however, the correctness of the modified Rydberg formula, in the form which I have independently discovered, is not yet disproved; for the direct determination of the three constants in the formula

$$\tau_n = A - B\,(n + c)^{-2}, \text{ or } \lambda_n = a + \frac{b}{(n + c)^2 - b},$$

in which $A = \frac{1}{a}$ and $\frac{B}{A} = b$, does not lead to the same values of B as the formula

$$\tau_n = A - Bn^{-2} - Cn^{-4}.$$

Since the deviations of the second constant B from a mean value are comparatively small for all the elements in both formulæ, Messrs. Kayser and Runge are led to remark that "Rydberg's assumption is possibly so far correct, that in the still

hidden true law this constant represents one and the same value throughout."[1]

Rydberg found that for all elements the curve determined by erecting ordinates proportional to the wave-lengths, at equal intervals corresponding to successive values of n as abscissæ, resembles a hyperbola, since it approaches lines parallel to the axes as asymptotes.

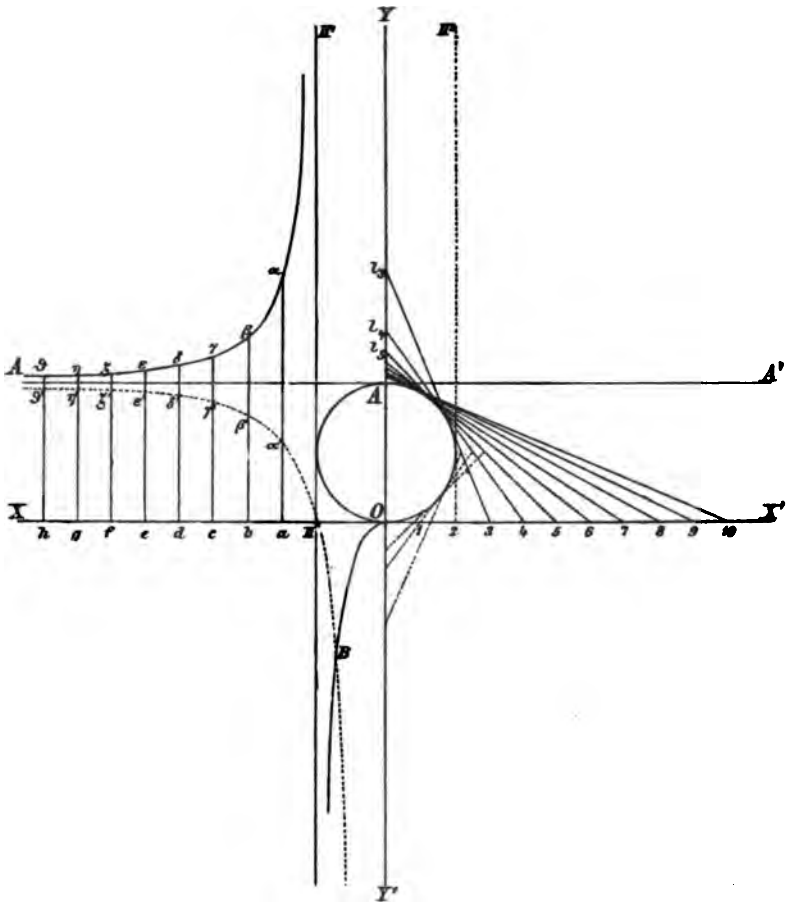
If we test the character of the curve for the simple hydrogen spectrum, where the relations are simplest and clearest, and take into account all (including negative) values of n, we shall find that the curve is of the third degree, with three asymptotes (see the figure). The single horizontal asymptote lies at the distance a above the axis of abscissæ. On each side of the axis of ordinates, parallel to the latter, and at a distance from it equal to $2n$, is a vertical asymptote. The curve itself has three branches: two of a generally hyperbolic form above the horizontal asymptote, separated from each other by the interval $4n$ between the vertical asymptotes, and a third between the vertical asymptotes, having its vertex at the origin, with infinite branches which form a transition to the hyperbolic curves above.

The curve of reciprocals of wave-lengths in the hydrogen spectrum (taking as unit $a = 4n$) is easily shown in its relations to the wave-length curve. It also is a curve of the third degree, and consists of only two branches, which as before resemble the hyperbola in form. They have the same horizontal asymptote as the wave-length curve, and a single vertical asymptote, which is the axis of ordinates. These branches pass through the intersections of the vertical asymptotes of the wave-length curve with the axis of abscissæ, and approach the axis of ordinates as asymptote below, having a cusp at infinity.

In the accompanying figure (Plate VIII) XX' is the axis of abscissæ, YY' the axis of ordinates, O the origin; AA' is the horizontal asymptote and II, II' and $2II^2$ are the vertical asymptotes; $\alpha\, \beta\, \gamma$, etc., is the wave-length curve of hydrogen; $a\alpha$ the wave-length γ_8, $b\beta = \lambda_4$, etc. The curve of reciprocals is $B\, II\, \alpha'\, \beta'\, \lambda'$,

[1] *Spectren der Elemente*, IV Abschnitt, 63.

PLATE VIII.



$\alpha\ \beta\ \gamma\ \delta\ \epsilon\ \zeta\ \eta\ \theta$: **Curve of Wave lengths.**
$\alpha\ \beta'\ \gamma'\ \delta'\ \epsilon'\ \zeta'\ \eta'\ \theta'$: **Curve of Reciprocals.**

etc., aa' being the reciprocal of λ_3, $b\beta'$ the reciprocal of λ_4 or $b\beta$, etc. Only half of each curve is drawn; the other half may be readily supplied, the curves being symmetrical with respect to the axis of ordinates.

A very simple construction of the hydrogen wave-lengths is shown on the right side of the figure. Let OA on the axis of ordinates represent the constant a, or the lower limit of the hydrogen wave-lengths, and let a circle be described having $AO = 3645.6$ Ångström units as a diameter; then if tangents are drawn to the circle from the points $n = 1, 2, 3$, etc., on the axis of abscissæ (the unit is taken to be $1n = \frac{1}{4}a = 911.4$), their intercepts on the axis of ordinates will represent the wave-lengths.

The correctness of the construction may readily be proved.

This construction may possibly be useful in throwing a new light on the mysterious phenomena of the spectral lines. and in leading to the right way of finding the real closed formula for spectral wave-lengths, in case it has not already been found in the formula of Rydberg.

The final impression, which our mind involuntarily receives in contemplating these fundamental relations is that of a wonderful mechanism of nature, the functions of which are performed with never-failing certainty, though the mind can follow them only with difficulty and with a humiliating sense of the incompleteness of its perception.

MINOR CONTRIBUTIONS AND NOTES.

NOTE ON A CAUSE FOR THE SHIFT OF SPECTRAL LINES.

I WOULD call attention to a cause for the shift of the lines that Messrs. Jewell, Humphreys, and Mohler have been investigating with so much skill and success, which is allied to Professor Schuster's suggestion[1] but is so far distinct that it is not disproved by the observation that the shift is independent or largely independent of the amount of the substance in the arc.

When a body is a source of electromagnetic radiations the frequency of its vibrations depends in general on the specific inductive capacity of the medium in which it is immersed. An electromagnetic oscillator performs oscillations that can be calculated from a formula of the form $N^{-2} \alpha L C$, where L is self induction and C is capacity. If the medium have a high electric inductive capacity C will be large and consequently N will be small. Now an increase in the pressure of a gas increases its specific inductive capacity and must in consequence alter to some extent the period of vibration of the molecules in it, if their period of vibration depends at all on electric forces due to constant charges. We can consequently conclude that here is certainly a *vera causa* for some shift towards the red in molecules causing light, for in them there can be no doubt that electric forces are at least a part of the forces affecting the periods of vibration.

We can see that the complete solution of the question from this point of view is very complex. On the molecular scale we cannot deal with a gas as a continuous medium having a definite calculable specific inductive capacity. It is a very complex question how far an average specific inductive capacity in its neighborhood would control the vibrations of an electric oscillator. It would depend on the extent to which the oscillator was or was not self contained. Now what is called the dimension of a molecule is a measure of the extent of its action on its neighbors and consequently of their reaction on it. There is consequently reason to expect that some such rela-

[1] This JOURNAL, 3, 292, 1896.

tion as has been observed should exist between the dimension of the molecule and the amount of the shift. In some of the cases I have tried there seems to be some connection between the refractive index of the gas and the amount of the shift, but I would not expect much connection of this kind to exist because the principal cause for a change in the specific inductive capacity would be the high pressure air present, which is the same in all the cases observed, and secondly because the refractive index is a measure of the average specific inductive capacity only, and from this alone we could not expect to calculate the amount of the shift in each case because, as I said, this latter will depend partly on how far this average specific inductive capacity is able to alter the vibration periods of the molecule. It is evident, for instance, from the experiments that the influence of the cause, whatever it is, on some of the calcium movements that underlie certain of the lines is much greater than its influence on other movements underlying other lines.

Everybody must feel the very greatest interest in this work. It is bringing us measurably nearer a knowledge of atomic movements and interactions, the great goal of modern physical research.

TRINITY COLLEGE, Dublin. GEORGE F. FITZGERALD.

NOTE ON A FORM OF SPECTROHELIOGRAPH SUGGESTED BY MR. H. F. NEWALL.

In a recent number of the *Proceedings of the Cambridge Philosophical Society*[1] Mr. Newall publishes an interesting suggestion for a new form of spectroheliograph.

After describing several instruments previously employed by M. Deslandres and the writer he suggests that some modification of Littrow's spectroscope with fixed slits would seem to offer obvious advantages for these investigations. The proposed spectroheliograph consists of a single telescope, which serves as both collimator and camera, with a grating (or train of prisms) attached by means of a suitable framework at the objective end. The slits are fixed on opposite sides of the eye-end of the telescope. Light entering the first slit meets a right-angle prism near the axis of the telescope, from which it is reflected into the collimator lens. The spectrum formed by the

[1] *Loc. cit.*, 9, 179, 1896.

grating is returned through the tube, falls upon a second right-angle prism, and is brought to focus on the second slit. By simply rotating the grating any desired line may be made to pass through this slit. The solar image and the photographic plate are in parallel planes, and remain fixed in position while the spectroheliograph is moved in the direction of its optical axis. Mr. Newall suggests that such an instrument be mounted like the bob of some forms of ballistic pendulums, with the slits vertical when at rest, the first slit bisecting the solar image formed by a coelostat. It is then to be set swinging with an amplitude slightly greater than the diameter of the Sun's image, and allowed to swing long enough to give a sufficient exposure.

As Mr. Newall remarks, a spectroheliograph embodying the Littrow principle was built for the writer some years ago. Mr. Newall's proposed instrument is decidedly superior to that particular piece of apparatus, which was designed to be used under circumstances such that movement as a whole was inadmissible. Since that time exactly such an instrument as that now described was suggested by Professor Wadsworth, in the course of our discussion relative to the design of the large spectroheliograph for the 40-inch refractor of the Yerkes Observatory. The plan of suspending the instrument like a pendulum, which was considered by the writer when the spectroheliograph belonging to the late Mr. Ranyard was being designed, was abandoned for the reason that the first slit would not remain parallel to itself during the exposure if the instrument were mounted in this way. Thus the lines in the photographed solar image which are due to dust on the slits would be curved instead of straight, and it would be troublesome, in measuring the photographs, to apply corrections necessitated by the curvature of the spectral lines. The distortion due to this curvature, while very considerable with prisms, is also by no means inappreciable with gratings. To remove this difficulty Professor Wadsworth has suggested that the spectroheliograph be suspended on some system of link-work giving a parallel motion. In this form it could be used to good advantage with a coelostat, though I am not sure that equally good results could not be secured with an instrument carried by ball bearing wheels rolling on rails.

After using many different forms of spectroheliograph, the writer is of the opinion that the type represented by the Ranyard instrument is probably as good as any other, at least for use in an invariable plane. For some reasons it would be of advantage to insert two right-angle

prisms, as Mr. Newall suggests, in order to make the motion parallel to the axis of the collimator, and to give more room for the photographic plate holder, or the camera box used with an enlarging lens. But it would probably be better to avoid the Littrow form, in spite of its simplicity, rigidity and compactness, unless the difficulties due to scattered light can be eliminated. It is true, as Mr. Newall remarks, that the central reflections can be partially or wholly stopped out, but the fact remains that the objective is illuminated by the sunlight passing through the first slit, and it is difficult to protect the sensitive plate from the scattered light.

The principal objection to the type of spectroheliograph just referred to is the considerable mass of the moving parts. This is not very serious when the instrument is used with a heliostat or coelostat, where it can easily be counterbalanced. But when it must be attached to the eye end of an equatorial the difficulties are much greater. For this reason experiments are now being made at the Yerkes Observatory to test one of the ingenious forms of moving slit suggested by Professor Wadsworth.[1]

It should be added that the spectroheliograph, whether used with an equatorial or a coelostat, should be so mounted that it can be rotated in position angle. Considering the distortion due to curvature of the spectral lines, which is inevitable in all forms of the instrument hitherto constructed,[2] it is a matter of some practical importance to be able to place the slit parallel to the Sun's axis before making an exposure.

Mr. Newall's suggestion that the spectroheliograph be made to move rapidly across the Sun's image several times during a single exposure seems to me a good one. Images free from the very objectionable lines due to inequalities of motion could undoubtedly be obtained in this way. The suggested pendulum support would be very convenient for exposures of this kind, but it may be doubted whether this advantage would offset the disadvantages already mentioned.

It is to be hoped that Mr. Newall will decide to have constructed a spectroheliograph embodying some of the new ideas.

GEORGE E. HALE.

YERKES OBSERVATORY,
February 1897.

[1] This JOURNAL, 1, 244, 1895.

[2] MR. W. H. WRIGHT, of the Yerkes Observatory, has suggested a method of correcting this distortion.

NOTE ON STEADY LIQUID SURFACES.

In some experiments carried out in the spring of 1894 in which it was necessary to obtain a sharp image of a line by internal reflection from a liquid, it was found impossible to use a polished glass surface of sufficient extent placed in contact with the liquid. It became necessary to test the conditions for damping of earth tremors and air disturbances.

Of several piers, one was selected showing the least disturbance on a mercury surface. Such a liquid surface, when the containing vessel was placed upon a thick layer of felt on a pier, showed most marked tremors at any time of night when local street traffic had ceased. A 4-inch collimator and telescope at an angle of 60° or more incidence and with the eyepiece removed, showed in a most interesting way the ripples produced by a switch engine three-quarters of a mile away in the dead of night. With the eyepiece in, the image of the slit appeared fairly sharp. A second float containing mercury, placed on the first surface, showed nearly the same effect. A water surface upon this showed the same. The ripples did not originate at the edge of the surface much of the time.

An attempt was then made to destroy the tremors by greatly increasing the inertia of the support, by piling up for a couple of feet alternate layers of thick felt and iron, weighing several hundred pounds. With the mercury surface resting upon this, and with the eyepiece of the telescope removed, ripples, arising from tremors, could still be seen under the most favorable circumstances.

Heavy masses supported by elastic means of different kinds showed the ripples still. A pneumatic arrangement gave the most promise, as evidently here, if the reservoir is large and the supporting area small, the transmitted changes of pressure can be almost eliminated; but in all cases of springs supporting masses, short period tremors seemed to be communicated through the spring itself and the envelope, in the case of air.

A different arrangement was then tried with success, consisting of four boxes fitting within one another with a clear space of from one to two inches between them. The outer one, about $50 \times 10 \times 10$ inches, was placed upon felt layers on the pier, and the space between it and the next filled with cylinder oil (medium). The second was ballasted with iron and the third placed within it upon layers of cotton. The

space between three and four was likewise filled with oil. Number four was ballasted and a support for a tube was placed within it on cotton layers. The whole arrangement was protected from air disturbances.

A horizontal tube, 50×2 inches, with capped ends and partly filled with water, showed no evidence of ripples under favorable circumstances. A telescope of 1-inch apertnre and an angle of incidence of 89°, so that the light was incident over the full length of the surface, showed a resolving power of about $1'$ for 1-inch aperture, the calculated limit. Of a number of different liquids, used without jacketing the tube, water was the only one which gave for internal reflection for this length of tube, clear definition. All gave good definition for external reflection. With mercury and water upon mercury the full resolving power of the telescope was obtained.

The results indicate that there is more chance of transmitting rapid vibrations through elastic supports than through very viscous floats. Elastic supports for masses of great inertia may protect from slow disturbances as well as floats, but the latter seem to damp all vibrations most completely.

Position and steadiness can be obtained, if necessary, by a light packing of cotton in the surface of the oil. This was found not to affect the result in definition. Little was gained by making the thickness of the layer of oil large. A viscous liquid was found much superior to any other, such as water or mercury, as the ripples in the latter are not damped rapidly enough, and communicate disturbances. Of course everything must be protected from air currents, particularly the surface to be observed, as these are some of the chief disturbing elements.

D. B. BRACE.

AWARD OF THE GOLD MEDAL OF THE ROYAL ASTRONOMICAL SOCIETY TO PROFESSOR BARNARD.

I TAKE great pleasure in announcing that the Royal Astronomical Society has awarded the gold medal to Professor E. E. Barnard, Astronomer of the Yerkes Observatory, for his contributions to astronomical science. These include his discovery of the fifth satellite of Jupiter, micrometric measures of planets, asteroids, satellites, nebulæ, and comets, numerous discoveries of comets, photographs of the Milky Way, comets, nebulæ, and other objects with a portrait lens, and other

important observations. All of his colleagues at the Yerkes Observatory unite in extending to Professor Barnard their heartiest congratulations upon this well-deserved recognition of his work.

GEORGE E. HALE.

ON THE MODE OF PRINTING MAPS OF SPECTRA.

THE following remarks are quoted from the report in the February *Observatory* of the discussion at the meeting of the Royal Astronomical Society on January 8. They are of interest in connection with Professor Kayser's proposal that the mode of printing maps and tables of wave-lengths, adopted by the Board of Editors of this JOURNAL in 1895, should be reversed.[1] Further expressions of opinion will be gladly received by the editors for publication in the ASTROPHYSICAL JOURNAL.

The order of decreasing wave-lengths has been followed throughout; and I much regret that many astrophysicists have recently decided to follow the reverse order of the pianoforte keyboard in the order of the spectrum lines. —*Rev. W. Sidgreaves.*

I was extremely pleased to hear Father Sidgreaves' opinion as to the place in which the red end of the spectrum should be drawn, because, like himself, I am a heretic on that point. The ASTROPHYSICAL JOURNAL has laid down the law that the red end should be to the right, but I think the whole analogy is the opposite way. I showed some slides of the spectrum of helium here some time ago, and in those slides the red end was put to the left, and this arrangement was criticised; but it was necessary it should be so, because I was dealing with the question of series of lines, and it seems to me we can only deal with a series of lines by beginning with the left end, in the same way as we begin on the left-hand side of the page of a book. There is also the analogy of the piano. I shall be glad to see a reversal of the decision of the ASTROPHYSICAL JOURNAL.—*Mr. Maunder.*

I think they are reopening the question.—*Mr. Newall.*

The delineation of the spectrum from left to right in accordance with the increase of wave-lengths was adopted by Kirchhoff, Thalén, and Angström, also by Huggins, Lockyer, Cornu, Dunér, Draper, Pickering, Rowland and others.—*Mr. McClean.*

On the subject of the arrangement of spectrum lines referred to by Mr Maunder, Mr. McClean, and Father Sidgreaves, I think that for the proper

[1] See this JOURNAL, 4, 306, November 1896.

representation of the spectrum scale the small wave-lengths ought, as in the high keys of a pianoforte, to be placed on the right.

—*Prof. Alexander Herschel.*

SALE OF INSTRUMENTS AND DRAWINGS FROM THE COLLECTION OF THE LATE M. TROUVELOT.

We desire to call attention to the fact that the following instruments and drawings, which belonged to the late M. Trouvelot, of the Observatoire de Meudon, are now offered for sale by his family.

(1) A photographic telescope with enlarging apparatus, especially designed for solar photography. The object glass, by Brashear, is of 15^{cm} clear aperture and $200^{cm}.8$ focal length, and is corrected for the region near G. The tube and other metallic parts are by Bardou of Paris. A brass dew-cap 50^{cm} long, provided with hinged cover, forms part of the instrument. The telescope tube is perforated by two openings 180° apart, for the purpose of allowing both sides of the objective to be brought to the same temperature. The tail-piece carries a tube moved by rack and pinion, with scale and vernier for accurate setting. There are two amplifying eyepieces by Brashear. No. 1 gives an image of the Sun 100^{cm} in diameter at a distance of 100^{cm}. No. 2 gives an image 20^{cm} in diameter at a distance of about 50^{cm}. The photographic camera attached to the lower end of the tube is provided with all necessary adjustments, and is designed to carry a plate $25^{cm} \times 25^{cm}$. It contains a special curtain-shutter for giving very short exposures. The adjustable slide in the curtain can be given any opening up to 1^{cm}. Attached to the telescope is a Secretan finder, with an eye-piece which projects the solar image upon a ground-glass supported in a brass cone. The price of this instrument complete is 5000 francs.

(2) A comet seeker of 10^{cm} clear aperture and 145^{cm} focal length. Near the center of the tube a large right-angle prism is mounted so that the observer always looks in a horizontal direction. The mounting is in the alt-azimuth form, and a hand wheel is provided for moving the telescope, which is suitably counterbalanced. A metal strap with pivot is so arranged that the instrument can be mounted upon a suitable column. The metal work of the tube is of polished and lacquered brass. A low power (Clark) eyepiece accompanies the telescope, which is offered for 1500 francs.

(3) The original pastel drawings of various astronomical objects made by the late M. Trouvelot. Many of these are familiar through the reproductions published in the United States, where the drawings were made.

For further information, intending purchasers should address M. Georges H. E. Trouvelot, 23, rue des Capucins, Meudon, Seine et Oise, France.

ERRATA.

THE following corrections should be made in Mr. Jewell's article in the December 1896 number of this JOURNAL:

Page 328, for *amplitude* read *azimuth*.

Page 335, Table IV, for βm read m.

Reviews.

Ueber einen Versuch eine electrodynamische Sonnenstrahlung, und über die Aenderung des Uebergangswiederstand bei Berührung zweier Leiter durch electrische Bestrahlung: J. Wilsing und J. Scheiner. *Wied Ann.* **59**, 782–792, 1896.

At the Astrophysical Observatory in Potsdam, Messrs. Wilsing and Scheiner have been making a careful search for the presence of long electromagnetic waves in the solar radiation. It was, from the outset, expected that, if such waves were emitted by the Sun at all, their intensity would be greatly diminished on passing through the Earth's atmosphere.

The determining factor, therefore, in the selection of a detector was *sensibility*. Accordingly Lodge's form of Branly's Coherer, a "bridge" of three steel wires, was selected. Of these three wires, two are laid parallel and the third is laid across the two; the battery and galvanometer are joined in series with the bridge thus formed. The whole was then placed in a metal case to shield it from outside disturbances. In the top of this case was an opening fitted with a metallic reflector, which could be used to direct any desired radiation upon the "bridge." This simple and extraordinarily sensitive instrument proved itself much like other sensitive instruments, viz., unreliable in its very small indications. A heliostat fitted with a metallic mirror directed the solar radiation toward the receiver. Two paper screens, transparent to long waves, kept out the heat and light.

As to results, nothing positive was attained. The indications due to solar radiation, if any, were less than the errors in reading the galvanometer scale.

This interesting attempt to extend the solar spectrum reminds us of a fact which cannot be over-insisted upon at this time, viz., there is a very wide difference between assuming on mathematical grounds and proving by experiment, the continuity of the properties, or even of the existence, of all waves intermediate between the very short ones photographed by Schumann and the very long ones studied by Hertz.

H. C.

Total Eclipse of the Sun, April 16, 1893. Report and Discussion of the Observations relating to Solar Physics. By J. NORMAN LOCKYER, *Phil. Trans.*, 187, pp. 551–618, 1896.

THE exceedingly interesting and important results obtained by Mr. Shackleton at the eclipse of last August in photographing the spectrum of the "flash" immediately preceding totality, have directed attention to the important part played by the prismatic camera in eclipse observations. The results secured by Mr. Shackleton will be described and illustrated in a subsequent number of this JOURNAL. At present we must confine our attention to the almost equally valuable results obtained by Messrs. Fowler and Shackleton at the eclipse of April 16, 1893. The reports of Messrs. Fowler and Shackleton, together with a discussion of the results by Professor Lockyer, are contained in a memoir recently published in the *Philosophical Transactions.*

The memoir opens with an introductory statement by Professor Lockyer, in which a brief historical sketch of the use of the prismatic camera in earlier eclipses is given. In 1871 Respighi and Lockyer first used this instrument for eclipse work. Previous to this time it had been employed by Fraunhofer in his early observations of the spectra of the stars, and later by Secchi in his stellar spectroscopic work and by Respighi in certain special observations of the Sun. In 1871 Resphigi used a single prism over the object-glass of his telescope, and Lockyer employed a train of five prisms without either collimator or observing telescope. At the beginning of totality Respighi saw the chromosphere in the lines C, D_3, F and G, and later three bright rings, which he considered to correspond with C in the red, 1474 in the green, and F in the blue. Of these the green ring was the brightest, most uniform, and best defined. Lockyer's observations were made 80 seconds after the beginning of totality. He saw the C ring very bright, 1474 and G faint, and F of intermediate intensity.

In 1875 photography was first employed in eclipse work with the objective prism, but the dispersion was so small that the results were of no great value as compared with those subsequently obtained. In 1878 no bright rings were recorded. In 1882 Dr. Schuster photographed a green ring corresponding to 1474, and a yellow one which he believed to coincide with D_3. In 1883 the same instrument used in the preceding year was employed, but gave no valuable results. The same camera was again employed in 1886, and recorded the spectra of

some prominences, but apparently gave no rings. In 1893 prismatic cameras were used by Messrs. Fowler and Shackleton, and with them photographs were obtained which are far superior to those secured at previous eclipses.

The prismatic camera used by Mr. Fowler at Fundium, West Africa, was one which had been in constant service at South Kensington for stellar spectroscopic work. It consists of a single prism of 45° refracting angle, supported at the position of minimum deviation in front of a photographic objective of 6 inches aperture and 7 feet 6 inches focal length. The correction of the object-glass, which is by the Brothers Henry, is such that the whole spectrum is in focus when the plane of the plate is normal to the axis of the camera. With the dispersion of the single prism the spectrum is about two inches long from H to K. The rings corresponding to the inner corona have a diameter of about seven-eighths of an inch. The objective and prism were mounted at the end of a strong mahogany tube of square section, which was attached to the declination axis of a 6-inch Cooke refractor. The plate holders were divided into three compartments, each taking a plate 4 by 6 inches. Between each exposure the slide was pushed forward so as to bring a fresh plate into position. The exposures were made by covering and uncovering the prism with a piece of thick card. During the eclipse thirty photographs were taken, with exposures ranging from "instantaneous" to 40 seconds. Six of these were made before and nine after totality.

At the Brazilian station Mr. Shackleton employed a prismatic camera consisting of a large photographic spectroscope deprived of its collimator, mounted on an iron table, in conjunction with a 12-inch siderostat. The optical train consisted of two 60° prisms of 3 inches aperture, and a Dallmeyer portrait lens of 3.25 inches aperture and 19 inches focal length. With this camera the length of the spectrum was 1.65 inches from $H\beta$ to K and the diameter of the Sun's image 0.176 inch. Each of the plate holders, of which three were provided, contained eight compartments for plates. These were successively brought into position by means of a rack and pinion. Twenty-four exposures were made, ranging in length from "instantaneous" to 60 seconds. Of these one was made before totality, and six after the end of the total phase.

The appearance of the photographs obtained in Africa is illustrated by the accompanying cut, reproduced from a positive on glass of one

of the photographs which was kindly presented to the reviewer by Mr. Fowler. It is seen that the chromosphere and prominences are remarkably well shown in a large number of rings. Of these, by far the brightest are those due to H and K, while the hydrogen rings are second to these in intensity.

In the photographs taken about mid-eclipse, some of which are reproduced in Professor Lockyer's memoir, the spectrum of the chro-

mosphere is not shown on account of the central position of the Moon. Such prominences as were high enough to be seen beyond the Moon's limb are represented in the photographs. One of the negatives faintly outlined a bright group of prominences in the *Hα* line, although the plates were not very sensitive in this part of the spectrum. Images of the prominences in D_3 were also shown. The spectrum of the corona appears from these negatives to be largely continuous, but some of the photographs show a nearly complete ring corresponding to 1474, and small portions of very faint rings. The continuous spectrum is brightest near the photosphere and fades out very gradually away from the limb. Little can be determined from these photographs regarding the wavelength of the point of greatest intensity, without a careful study of the curves of sensitiveness of the plates employed. On the ordinary plates, the position of maximum intensity is about $\lambda 450$, while on the isochromatic plates there is another maximum about $\lambda 560$. At these points the continuous spectrum extends farthest from the photosphere, on three of the plates reaching a distance of about two-thirds of the Sun's diameter.

The 1474 ring is shown in four photographs, one of them made on ordinary and three on isochromatic plates. This ring reaches its greatest height some 45′ above the Moon's limb, on a plate made about the middle of totality with an exposure of 40 seconds. The variation of the intensity of the ring is very marked, as it is clearly visible near the poles and quite bright in the equatorial regions. The position of

greatest brightness corresponds closely with the brightest regions in the direct photographs of the corona. The ring seems to have no connection with those due to the prominences, and there was no trace of the 1474 line in the spectrum of any of the prominences The memoir does not state that the 1474 ring showed any trace of structure corresponding to the rays and streamers shown in the direct photographs of the corona.

In addition to 1474 several fainter coronal rings are shown, which can be easily distinguished from the rings due to the chromosphere and prominences, as their points of maximum luminosity never coincide. Moreover, the chromosphere rings are sharply defined, while those due to the corona are hazy and indistinct. The intensities of these rings fall off rapidly in going outward from the Sun's limb. On account of the short focal length of the object-glass used in Brazil, the images of the coronal rings obtained with it are much brighter than those photographed in Africa. The Brazilian negatives taken about the middle of totality give the 1474 ring with great intensity and sharply defined outline. A comparison of this ring with Professor Schaeberle's photographs of the inner corona shows that the brightest parts of the ring correspond with the brightest parts of the corona, where the continuous spectrum is most intense.

The reviewer has previously had occasion to refer to these same photographs in discussing the nature of the so-called "white prominences."[1] They admirably illustrate the differences in the intensities of lines in the spectra of various prominences. In certain cases prominences are shown in the H and K lines which are either extremely feeble or altogether lacking in the hydrogen lines. Thus we have certain proof that prominences exist, which when seen with the naked eye would have rather a lilac than a red color. As has been pointed out in the paper just referred to, the "white prominences" observed by Tacchini and others can probably be explained in this way.

In Part II, which consists of a discussion of the observations, Professor Lockyer first considers the relative advantages of the slit and slitless spectroscopes for eclipse work. With the former, lines lying close together are less likely to be confused through overlapping of the images, feeble lines have a better chance of being recorded, and the dark lines due to reflected sunlight in the corona can be shown. The prismatic camera, on the other hand, gives results which are at the

[1] This JOURNAL, 3, 374, 1896.

same time pictures of the various phenomena and images of their spectra. The prominences are shown in their proper positions, and their radiations are not confused with those of the corona. The light of the prominences and corona, scattered by our own atmosphere, instead of producing false lines in the spectrum, as in the case of the slit spectroscope, is practically eliminated by the prismatic camera. Further, as is also the case with stellar spectra, there is a considerable saving of light due to the absence of the slit and lenses used with the slit spectroscope. As the results recently obtained by Mr. Shackleton best illustrate, the prismatic camera is admirably adapted for photographing the "flash" at the beginning or end of totality. If the slit spectroscope were used for this purpose, the adjustments would have to be made with extreme care in order to obtain similar results, while with the slitless instrument no special adjustments are required.

The coronal rings photographed with the prismatic camera, with the exception of that belonging to 1474, are very feeble, and their wavelengths cannot be very accurately determined. On the African photographs eight rings of this kind were found. These correspond in a general way with lines photographed by Dr. Schuster with the slit spectroscope in 1886. Many other lines have been photographed in the corona, but while some of these are probably genuine, others are undoubtedly due to atmospheric glare. On account of the uncertainty regarding the wave-lengths of the corona lines, Professor Lockyer has not hitherto been able to determine whether they are represented by dark lines in the solar spectrum. He remarks, however, that if present at all, they are among the feeble lines.

Some stress is laid on the apparent absence of the 1474 ring from the spectra of the chromosphere and prominences. Professor Lockyer concludes that when 1474 is seen at the Sun's limb without an eclipse, the spectrum of the corona itself is really observed and not that of the chromosphere. In support of this he states that he is not aware of any observation of the *form* of the prominences in 1474 light. It is true that such observations are very uncommon, but a case of this kind has been described by Fenyi[1] in a brilliant eruptive prominence observed in the vicinity of the great spot-group of February 1892, when it was at the limb. The form of the base could be distinctly seen in the 1474 line up to a height of 33″. Again, 1474 appears in the solar spectrum as a dark line, and there seems to be no good

[1] *A. and A.*, 11, 432, 1892.

reason to suppose that it does not belong to the spectrum of the chromosphere, where it is always visible.

At this eclipse, as at all others where the prismatic camera has been used, H and K were not recorded as rings in the coronal spectrum. They have frequently been photographed across the corona with slit spectroscopes, but it is now generally believed that this was due to scattering of the light of the chromosphere and prominences in our own atmosphere. It can now in all probability be considered as definitely established that the H and K lines do not properly belong to the coronal spectrum. Dr. Schuster reached this same conclusion in 1886.

As has already been remarked, the photographs show a strong continuous spectrum due to the corona. Professor Lockyer is inclined to consider that this is not truly a continuous spectrum, but rather one filled with maxima and minima of brightness, producing a ribbed appearance. This conclusion is, of course, not based upon the results obtained with the prismatic camera, but rather upon a hasty observation of his own in 1882. Until this observation has been confirmed the spectrum will probably be considered to be continuous.

In his discussion of the variability of the spectrum of the corona, it cannot be said that Professor Lockyer reaches any very certain conclusions. In 1871 the 1474 ring appeared to him very bright, but in 1878 he did not see it at all. It was, however, seen as a faint line by Professor Eastman. It was also seen in 1882, 1883 and 1893 near times of Sun-spot maxima, and in 1889 by Professor Keeler near a minimum. While the observations seem to show that its brilliancy was rather less at eclipses which occurred near the Sun-spot minimum, it can hardly be said that a periodic variation in brightness can be considered as established, especially when it is remembered that the 1474 ring photographed in 1896 was quite as strong as that photographed in 1893.

Experiments made by Mr. Fowler with the prismatic camera have shown that under certain conditions false rings can be both seen and photographed. These results have thrown some doubt upon the origin of rings which have been ascribed to hydrogen, though it would appear that in one or two eclipses hydrogen was probably present in the inner corona.

The wave-length tables which conclude the memoir contain about 250 lines. All lines seen on any of the negatives are recorded, whether

they belong to the spectrum of the chromosphere or prominences. Many of these lines have previously been observed in full sunlight or at previous eclipses, but a large number are new. The intensities are recorded on a scale of 10, the strongest line in each negative, irrespective of exposure, being given this maximum value. The great majority of lines are shown to increase in intensity as they approach the photosphere, but great stress is laid on the fact that a few lines seem to gain in brightness in passing out from the limb. It should be remarked, however, that results of this character, which are directly opposed to those ordinarily obtained in daily observations of the spectrum of the chromosphere and prominences, should be received with great caution. It is of course well known that prominences are not infrequently brighter at the top than at the bottom, so that the lines in their spectra have their maximum brightness at some distance from the Sun's limb. But this depends upon local peculiarities of structure, and can hardly be considered to have any relation to hypothetical "layers" in the solar atmosphere. In general, lines in the spectrum of prominences are brightest near the base, and brighter still in the chromosphere. Professor Lockyer bases his conclusion that the "prominences must be fed from the outer parts of the solar atmosphere" in part on the fact that the spectrum of a very bright metallic prominence shows lines which are absent from the spectrum of the chromosphere, not immediately beneath the prominence, but some distance away. The reason given for making such a comparison is that "it is fair to consider the base of the chromosphere homogeneous" (p. 607). Those who have been accustomed to observe the spectrum of the Sun's limb below eruptive prominences will not be likely to agree in this opinion.

The results obtained by Mr. Shackleton at the 1896 eclipse render unnecessary a discussion of the bearing of the 1893 results on the question of the "reversing layer." The photograph of the "flash" spectrum, which has been exhibited by Professor Lockyer to the Royal Society, will soon be reproduced in this JOURNAL. It is stated by a well-known writer in the London *Times* that there can no longer be any doubt regarding the existence of the stratum whose spectrum was first observed by Professor Young in 1870.

G. E. H.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

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NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, with be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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PLATE XI.

MAIN ENTRANCE OF THE YERKES OBSERVATORY.

THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME V | APRIL 1897 | NUMBER 4

SPECTROSCOPIC NOTES.

By W. W. CAMPBELL.

THE HARVARD STAR, Z CENTAURI.

IN December 1895, the *H. C. O. Circular* No. 4 announced that a "new star" had just been discovered by Mrs. Fleming, from an examination of the Draper Memorial photographs taken at Arequipa, Peru. The *Circular* stated that the star was situated very near the nebula *N. G. C.* 5253; that no trace of the star could be found on 55 plates taken from 1889 May 21 to 1895 June 14; that its magnitude on 1895 July 8 and July 10 was 7.2, and on 1895 December 19 was about 11; that an examination with a prism on December 19 showed that the spectrum was monochromatic, and closely resembled that of the adjacent nebula; and that, like the new stars in Cygnus, Auriga and Norma, this star appeared to have changed into a gaseous nebula.

The star was at once observed at Mt. Hamilton. It was found to follow the nucleus of *N. G. C.* 5253 by $1^s.4$ and was north of it $18''$. Its position for 1875.0 was[1]

$$\alpha = 13^h\ 32^m\ 51^s.9, \quad \delta = -30^\circ\ 59'\ 58''.$$

On the nights of 1895 December 22 and 29 I examined the

[1] *Ast. Jour.*, 16, 85.

spectrum of the star—then 11.2 magnitude—and was reasonably certain the spectrum was continuous, but the seeing was too poor to permit a definite decision. It was certainly not nebular. On the morning of February 8, 1896, the conditions were good, and I carefully examined the spectra of the star and the adjacent nebula, using the large spectroscope and 60° crown prism. The nebula's spectrum was of the usual type, the lines at $\lambda\lambda$ 5007, 4959 and 4862 having their usual relative intensities. The line near λ 4690 seemed to be present, as in the case of *N. G. C.* 7027 and *G. C.* 4964. The spectrum of the Harvard star was *continuous*, though very peculiar. The maximum visual intensity was in the yellow-green, the green-blue was very faint, while the blue was surprisingly strong. In fact, the blue was very much brighter visually than the green-blue. The spectrum was relatively very faint from about λ 5200 to λ 4600. There was no trace of the nebular lines visible, nor of the $H\beta$ line. There was some evidence of bright lines or of irregularities in the brightest portions of the spectrum, but the light was too weak to enable me to decide. The slit was at right-angles to the line joining the star and the nebula. By pressing against the telescope the two spectra were alternately brought into view. The nebular spectrum thus formed a good basis of comparison, and the star spectrum in no wise resembled it.

The Harvard observation of the spectrum was made on December 19 with the 15-inch telescope, when the star was of the 11th magnitude, very low in the sky and near the Sun. The continuous spectrum under such circumstances would be exceedingly faint. The star and nebula are less than 30′ apart. Is it not possible that the observed spectrum was that of the nebula, and not that of the star?

On June 11, 1896, Professor Hussey observed that the star had decreased in brightness to 14.4 magnitude, and that it was surrounded by a faint, irregular nebula which seemed to extend continuously to the main nebula south preceding. On July 9 he observed the star to be of the 16th magnitude, and the nebulosity surrounding it was plainly seen to be continuous with the

bright adjacent nebula, *N. G. C.* 5253. That the nebulous background was not seen earlier was probably due to the overpowering light of the star. On January 4, 1897, Professor Hussey looked for the star, without success: it was fainter than 16¼ magnitude, and invisible.

Some writers have contended that this star is not a "new star," but that it is identical with *Cord. DM.* $-31^\circ 10536$,[1] observed on four nights in 1885–92 at Cordoba. While I do not want to enter upon a discussion of this question—at present unsolved and not now capable of solution, apparently—I may perhaps express my opinion that all the evidence available points to the identity of the nebula *N. G. C.* 5253 and the star *Cord. DM.* $-31^\circ 10536$. The evidence that the Harvard star was observed previous to 1895 July 8 is confined to the single Cordoba date, 1887 April 12.

If the star is simply a variable, as some writers contend, its period must be very long, or its variations very irregular.

If the star is to be classed with the "temporary" stars, it is not analogous to the new stars in Cygnus, Auriga and Norma, but rather to the star of 1885 in the Andromeda Nebula.

THE SPECTRUM OF MARS.

My visual spectroscopic observations of Mars and the Moon in 1894, under extremely favorable circumstances, led me to conclude that the two spectra were apparently identical, so far as visual estimates of the intensities of the telluric lines were concerned. My paper on the subject stated the conclusions to be drawn from the observations as plainly as it would be possible even now to state them. Nevertheless, they were misunderstood persistently by many reviewers, and I beg to re-state them here, viz.:

While the polar caps are conclusive evidence of the presence of atmosphere and vapor (probably water-vapor) on Mars, yet these do not seem to exist in sufficient quantities to have been detected by any spectroscopic observations thus far made; and

[1] *Ast. Jour.* 16, 16, 106, 165, 166.

my observations indicate that the density of the atmosphere at the surface of Mars is not more than half as great as the density of our atmosphere at the summit of the Himalaya Mountains.

Thus far, all the observations were visual, though there were plates sensitive to the light from the region of the important δ vapor band. In March 1895 I obtained a few photographs of the spectra of Mars and the Moon, on Cramer's isochromatic plates, using the large Brashear spectroscope and a 60° crown prism. The photographs covered the region of the δ band. There was no visible difference in the spectra of the two objects, though the conditions were not first-class.

On October 22, 1895, using the apparatus described above, I obtained a long series of photographs of both spectra. The dew-point for the night was 0° Centigrade. Some of the negatives were copied on lantern-slide plates, for the purpose of increasing the contrasts in the spectra. Neither the original negatives, nor the positives on slow plates, revealed any differences in the two spectra. However, a comparison of the plates corresponding to high and low altitudes, convinced me that the photographic method *with low dispersion* is not so sensitive as the visual method with the same dispersion. On December 18, 1896, I obtained a few photographs, using a fourth-order grating. It was necessary to use a rather wide slit, and the negatives were considerably underexposed, though comparable in the δ region. There was no visible difference in the spectra, but the result is purely negative, for two reasons: (*a*) The negatives are not as dense as they should be; and (*b*) I was unable to secure photographs at low altitudes, to test the sensitiveness of the method. I believe the photographic method with high dispersion is fully as sensitive as the visual method with low dispersion; but to what extent it is more sensitive I cannot say. A train of three flint prisms would have been much more efficient than the grating, but such a train was not available.

There has been some discussion as to whether high or low dispersion should be used in such a problem as this. Not to enter upon a consideration of the general question, I may per-

haps make one or two remarks. In the photographic study of a spectrum, such as that of Mars, the question of brightness does not enter, except as it affects the exposure time. When the visual method is used, the question of brightness does enter. It is then a question of getting *a little something* with low dispersion, or *nothing at all* with high dispersion. It has been my experience that those who have not observed spectra at night invariably overestimate the brightness of those spectra.

COMET 1895 IV (PERRINE).

Visual observations on November 17, 1895, showed the yellow, green and blue bands of carbon, with their usual relative intensities, together with a strong continuous spectrum.

A photograph taken December 8, 1895, showed the following features:

The blue carbon band, unresolved, maximum near λ4690.

λ 4366 bright line, easy.

λ 4313 " " faint.

λ 4298 " "

λ 4214 " " very easy, cyanogen.

λ 4196 " " easy, cyanogen.

Traces of several bright lines between λλ 4100–4000 (cyanogen?).

λ 3881 brightest line on plate, cyanogen.

λ 3870 very bright line, cyanogen.

Continuous spectrum between λλ 4700–4000, which has a fluted appearance, as if caused by the principal groups of absorption lines in the solar spectrum, notably the group at G.

COMET 1895 V (BROOKS).

On November 22, 1895, visual observations showed that the spectrum was of the usual character. The spectrum was too faint to photograph.

COMET 1896 I (PERRINE).

On February 19, 1896, the visual spectrum was of the usual character. A photograph recorded the bright cyanogen lines

at $\lambda\lambda$ 3881 and 3870. No other lines were recorded, on account of the faintness of the comet, which was not visible to the naked eye.

COMET 1896 III (SWIFT).

On April 30, 1896, the visual spectrum was of the usual char acter. The spectrum was too faint to photograph.

COMET 1889–96 (BROOKS-JAVELLE).

Visual observations were made on August 15, and October 6, 1896. The comet was about 13th magnitude. The continuous spectrum was plainly visible, and I was pretty certain that a trace of the green carbon band was visible, but not absolutely certain. There was no doubt that the continuous spectrum was relatively much stronger than the gaseous carbon bands in this comet, than in any of the other comets I have observed, except in the case of Holmes' comet of 1892.

These comet photographs and many of the visual observations, were made with the 12-inch telescope and the large Brashear spectroscope mounted in a wooden case, using a 60° crown prism. This combination is very effective for photographing comet spectra, except that the clock and slow motions are unsatisfactory, and render the guiding very difficult. Further, this combination permitted me to make the observations without interfering with the regular spectroscopic work in the large dome. An extensive and expensive equipment is not necessary for the study of comet spectra, and the subject is seriously neglected. I desire especially to call attention to the importance of observing the spectra of periodic comets, both visually and photographically, at every opportunity. It is a good working hypothesis that the continuous spectrum is relatively stronger in periodic comets than in parabolic ones. As a comet approaches the Sun, its more volatile constituents are excited, electrically or otherwise, and are probably driven off permanently from the mass of the comet. For a parabolic comet this effect would be temporary, while for a periodic comet it would go on constantly, under

the Sun's influence; in which case it would seem that the bright-line spectrum of a periodic comet should gradually become less prominent. This view is supported by the observed spectra of Comet III, 1892 (Holmes) and Comet 1889–96 (Brooks-Javelle), and possibly by the meagerness of carbon in meteorites.

The four comet spectra which I have thus far been able to photograph, viz.,

1893 II (Rordame),
1894 II (Gale),
1895 IV (Perrine),
1896 I (Perrine),

have been identical so far as the different intensities of the four permitted comparison. All were parabolic comets.

NOVA AURIGÆ.

Occasional observations for the magnitude of the new star of 1892 in Auriga have been made. No change in brightness has been recorded since 1892.

In Vol. I., No. 1, of this JOURNAL I called attention to the remarkable changes going on in this star's spectrum. It was shown that the bright lines λ4360 and λ5750 which were very bright in August 1892 had become very faint in 1894. No photographs have been secured since November 1894, but visual observations show that the change in the line λ5750 has been progressive. The observed intensities of six of the principal bright lines have been as follows:

	$H\gamma$	λ4360	$H\beta$	λ4960	λ5010	λ5750
1892 August and September	0.1	0.8	1	3	10	1
1894 May 8	0.1	0.3	1	3	10	0.4
1894 September 7	0.1	0.2	1	3	10	0.4
1894 November 28	0.1	0.1	1	3	10	0.3
1896 August 15	—	—	1	3	10	0.1
1896 October 6	—	—	1	3	10	0.1

At the date of the last observation the line λ5750 was difficult to see at all.

It is especially significant that the lines λ4360 and λ5750 should be the ones to change. The first measures of the spectrum in August 1892 showed unmistakably that it was the spectrum of a nebula. At first, however, the lines λ4360 and λ5750 did not seem to exist in the old nebulæ. But photographs of their spectra at once showed the line λ4360 in five well-known nebulæ, and visual observations showed the line λ5750 in three nebulæ. These lines were strong in the *Nova*, but relatively faint in the old nebulæ. They have now become relatively faint, in fact practically invisible, in the *Nova*. The spectrum of the new star has lost its anomalies: it is now of the ordinary type of nebular spectrum, save that the lines remain broad, as they have always been described.

As my apparatus has been arranged, it has not been convenient to re-measure the wave-lengths of the principal nebular lines since November 1894. The last few measures secured were made with a dense 60° flint prism and magnifying power 26—a combination much preferable to the grating and low power employed in the earlier measures.

While the spectroscopic observations of *Nova Aurigæ* show it to be *truly nebular*, there has been a question as to whether the nebulosity is *actually visible* in the focal image of a telescope.

When the reappearance of the *Nova* was observed on August 17, 1892 by Messrs. Holden, Schæberle and Campbell, "all the observers agreed that its appearance was different from that of other stars of the same magnitude."[1] Later Professor Barnard announced[2] that the object was "really a small bright nebula with a 10th magnitude nucleus. . . . . With the micrometer the nebulosity was found to be 3″ in diameter—a fainter nebulosity still surrounded this and was perhaps ½′ in diameter."

Mr. Newall suggested[3] that the nebulous appearance was not real, but was due to the chromatic aberration of the object-glass, and that the image was truly stellar. This suggestion was

[1] *A. and A.*, 11, 715.

[2] *A. and A.*, 11, 751.

[3] *Nature*, 46, 489.

repeated and carefully elaborated by Professor Vogel.[1] Dr. Huggins,[2] observing with a reflecting telescope, which is free from chromatic aberration, saw the image as a stellar point.

The focal image of the *Nova* in the 36-inch telescope certainly looked substantially as Professor Barnard described it.[3] But further consideration of the problem, together with actual experiments on the *Nova* and on the Wolf-Rayet star $+30°3639$,[4] soon convinced me that the 36-inch telescope, with its strong chromatic aberration, was not suitable for deciding this question definitely. For if any one of the numerous monochromatic images were brought into focus, all the others would be out of focus, and would combine to form a halo surrounding the central image. The yellow image at $\lambda 5750$, so long as it remained bright, augmented the difficulty.

I therefore determined to estimate the diameter of the *Nova* by observing the width of its spectrum. Observations for that purpose were made in the fall of 1893 and of 1894. The rather coarse micrometer wire was placed lengthwise of the spectrum, and its width was such as just to occult the principal nebular line when the atmospheric conditions were fair. From the known width of the wire and the proportions of the spectroscope and telescope, the angular width of the wire was computed to be 1¼ seconds of arc. On none of the nights utilized was the seeing perfect; but I attempted to eliminate the effect of imperfect seeing by observing, in the same manner, the continuous spectrum of a star so selected that its spectrum at $\lambda 5010$ and the principal nebular line would be of about equal intensities. In every case the two spectra were practically of the same width, thereby indicating that *the focal image of Nova Aurigæ is stellar*. At the same time it must not be forgotten that *Nova Aurigæ* is a true nebula: the spectroscopic evidence is indisputable.

[1] *Über den neuen Stern im Fuhrmann*, Berlin, 1893.

[2] *A. and A.*, 13, 314–315.

[3] *A. and A.*, 12, 419.

[4] This star has a hydrogen atmosphere, 5″ in diameter. *A. and A.*, 13, 461.

The publication of these observations of the *Nova* has been unduly delayed—at first from a desire to repeat them on a first-class night, and later by the hope that the 36-inch Crossley reflector would be available for repeating them. As soon as the reflector is available I shall endeavor to get its testimony on this interesting question.

LICK OBSERVATORY,
UNIVERSITY OF CALIFORNIA,
March 3, 1897.

ON THE SPECTRUM OF HYDROGEN.

By H. KAYSER.

IN the Harvard College Observatory *Circular* No. 16 I see that Professor Pickering has come to the conclusion that the lines he discovered in the spectrum of ζ Puppis belong to hydrogen, because he is able to represent the old hydrogen series and the new lines by one formula as a single series. This possibility shows better than anything else could do the correctness of my former statement, that the old hydrogen series and the new one end at nearly the same point. But I am sure that the representation of the two series as a single one is incorrect. My arguments are the following:

1. The analogy with all the other elements, which have two series ending at the same point in the spectrum.

2. The different appearance of the lines of the two series; in every true series the lines have the same character, and become fainter as the shorter wave-lengths are approached.

3. The different conditions of appearance; this difference is so great, that we are hitherto unable to produce the second series.

4. For all the elements the second constant in our formula $\frac{1}{\lambda} = A - Bn^{-2} - Cn^{-4}$ has nearly the same value, so nearly indeed, that Rydberg believed the value to be exactly the same. But if we unite the two hydrogen series, then this constant has for hydrogen a value four times greater than for any of the other elements.

All these arguments seem to show conclusively that we must assume two series in the spectrum of hydrogen; it then corresponds admirably with the other elements.

BONN, February 2, 1897.

THE CAUSE OF THE DARKNESS OF SUN-SPOTS.

By J. Evershed.

The most generally received doctrine as to the constitution of the Sun is probably that in which the entire internal mass of that body is regarded as being in a gaseous condition; the temperature, below the photospheric layer, being above the critical point of all known substances. The low mean density is accounted for by supposing that the temperature increases rapidly with the depth below the surface, the expansive energy of the internal gaseous nucleus largely counteracting the enormous force of compression due to gravity.

It appears to be pretty generally admitted, too, by recent writers, that the photosphere is a surface of condensation; a region, exposed to the cold of space, where elements of high boiling point, such as those of the carbon group, are precipitating from the gaseous state and forming clouds of highly emissive solid or liquid particles.

I propose in this paper to discuss the question as to the cause of the relative darkness of Sun-spots on the basis of these fundamental ideas, and with special reference to the recent work of W. E. Wilson on the "Thermal Radiation of Sun-spots."

Most spot theories in vogue at the present time attribute the blackness of spots to masses of relatively cool vaporous material which absorbs the intense light of the underlying photosphere. Thus in Secchi's theory a spot is regarded as a kind of sink in the photosphere, ihto which the materials which have been erupted in the neighborhood are settling down again into the body of the Sun, forming a great cloud of cool absorbing vapors. Faye believes spots to be vortices set up by the relative drift of adjacent portions of the photosphere, the dark absorbing material accumulating in the vortex by reason of the indraught. Oppolzer likens a spot to a disturbed region in our atmosphere in which great contrasts of temperature arise; and he explains the

obscurity in the same way as a result of increased absorption by relatively cool vapors.

Many other theories have been proposed in which absorption is regarded as the principal factor in causing the darkness, and the evidence afforded by the spectroscope seems always to have been taken as practically demonstrating the truth of this hypothesis.

But absorption as ordinarily understood is in many respects very difficult to reconcile with the common features of spot formation. The well-defined structure and abrupt transitions in passing from photosphere to penumbra, and from penumbra to umbra, points rather to the *absence* of the bright photospheric clouds from the spot, than to their suppression beneath a mass of absorbing material; and seems much more suggestive of an actual rent in the photospheric layer through which a less luminous region is revealed.

Quite recently in a paper on the "Level of Sun-spots,"[1] read before the British Astronomical Association, Mr. Maunder argues that absorption can have but little effect in causing the spot darkness, for whether the spot be regarded as a depression or an elevation compared with the photosphere, the obscuring effect of an absorbing layer would be vastly increased when near the Sun's limb as compared with its effect at the center of the disk, owing to the foreshortening; and the greater the area of the spot the more noticeable would this become, so that in many cases the entire spot would appear as black as the umbra when near the limb. As this is not the case at all, the conclusion is drawn that diminished radiation rather than increased absorption is mainly operative in a spot.

In the same paper Mr. Maunder suggests that a spot may be regarded as a region of high temperature in which the condensation of highly incandescent carbon does not take place to the same extent as in the photosphere, the diminished radiation being due to the relatively low emissive power of the gaseous contents of the spot; just as in an ordinary gas burner the pre-

[1] *Jour. B. A. A.*, 7, No. 3.

cipitation of solid carbon produces a bright luminosity, whilst the purely gaseous portion of the flame glows but feebly.

This explanation of spot darkness certainly harmonizes very well with the observed structure of spots and with many of the attendant phenomena, such as the great brilliancy of the faculous bridges and the surrounding faculous region; the intensification of the H and K lines and frequently of the hydrogen lines over the entire spot region; all of which suggest that a spot is really a center of relatively high temperature.

Unfortunately it is open to a very serious objection when we consider the application of Kirchhoff's law to solar conditions. For suppose we liken a spot to a non-luminous Bunsen flame, or better, to a pure hydrogen flame burning in air, and a bright facula bridging the spot to a platinum wire held in the flame. The analogy would at first sight appear to be a very striking one, the hydrogen flame emitting a very feeble continuous spectrum and the glowing solid a very brilliant one, although no hotter than the flame. But yet according to Kirchhoff's law the feeble emissive power of the gas is exactly compensated by its feeble absorptive power, so that if we were to increase the thickness of the non-luminous flame indefinitely the brightness would increase, until finally, it would equal that of the glowing solid; even that of a theoretically "black" solid which has the highest emissive power. This condition would be reached when the radiating gas was of such thickness as to be entirely opaque to transmitted light.[1]

In the case of the Sun-spot, therefore, we should expect that the immense and practically unlimited depth of the interior gases would compensate for their relatively feeble radiating power, even if we took no account of the much higher temperature and high state of compression of the interior regions. There seems to be no escape from this difficulty, even if we imagine the interior of the Sun to be absolutely non-luminous, for then,

[1] The cumulative effect of a great thickness of radiating gas can easily be shown with a row of Bunsen flames such as are used in tube furnaces. If these are observed "end on" the brightness is seen to increase in proportion to the number of flames, or very nearly so.

according to Kirchhoff, it will also be absolutely transparent, and the photosphere on the opposite side would be seen through the spot opening.

Again, if the internal gases are so compressed as to be practically opaque like solids, then they must radiate like solids, they cannot continue to accumulate the energy acquired by absorption indefinitely. Thus we seem driven back again to some modification of the absorption hypothesis, unless we find that the ordinary laws of heat exchange are not applicable under solar conditions.

The structural characteristics of spots might perhaps be explained on the absorption hypothesis by supposing that the cooled absorbing material was situated at a considerable depth, being partly overlaid and encroached upon by the photosphere, the spot opening being at the same time filled up with dark material; and it would be natural to suppose this absorbing material to be the same as that which everywhere covers the Sun, producing the absorption at the limb, and giving rise to the mottled appearance of the disk due to variations in level of the photospheric clouds in this smoke-like veil. Thus there would be no real distinction to be drawn between a well-developed spot and the minute pores and interspaces between the photospheric clouds. It will be shown later, however, that there is a very marked difference in the character of the spot darkening and the general shading at the limb. It is clear that if a spot is really an accumulation of absorbing vapors it must be cooler than the photosphere, whilst if on the other hand, it is an opening where the photospheric clouds have been evaporated, we must regard it as being as hot as or hotter than the surrounding region. Evidence in support of the absorption hypothesis has been frequently derived from the widened lines seen in spot spectra, which are supposed to indicate a lower temperature in the absorbing gases. But the widening is at the most very slight; a proportionally slight increase in the depth of the gases concerned will equally well account for it. Furthermore, only a very small proportion of the lines in the spectrum are widened

or intensified; probably many others are weakened or suppressed altogether even when they do not appear as *bright* lines. It has not, perhaps, been sufficiently realized that a large proportion of the light we are dealing with in the spectrum of a dark nucleus is not derived from the spot at all, but is simply photospheric light reflected from the sky; the contrast between the umbra and the sky illumination outside the limb being in many cases almost inappreciable. Thus the majority of the Fraunhofer lines in the umbral spectrum may be spurious lines; could we remove our atmosphere and wholly isolate the umbral light, it is quite possible that the spectrum would be found to be, in the main, an emission spectrum.

However this may be, the widened lines are evidently not a satisfactory criterion as to the relative temperature of spots and photosphere, and the slight extra amount of gaseous absorption implied by their presence can have practically no effect on the darkness of spots. This is obviously due to the general darkening, which is apparently continuous all along the visible spectrum and may or may not be the result of absorption. The resolution of a portion of the spot band by Professor Young into innumerable closely crowded dark lines with occasional bright intervals,[1] would seem to point to absorption, but absorption by gaseous rather than solid or liquid matter.

In the opinion of the writer, no satisfactory explanation of spot darkness is likely to be arrived at until the spot band itself has received the closest investigation, both in the visible and invisible regions of the spectrum, particularly with regard to the relative intensity and character of the band and quite apart from the question of widened lines or bright lines, which can only give information as to the condition of the gases in the overlying reversing layer and chromosphere, and which taken all together can have but little influence on the general radiation of the spot.

THE THERMAL VALUE OF THE SPOT RADIATION.

The measurements of total radiation from spots by Langley,

[1] YOUNG, *The Sun*, 4th ed., p. 323.

using a bolometer, and recently by W. E. Wilson with a radio-micrometer, do not give any direct information as to the relative temperatures of photosphere and spots; the relative emissive powers being unknown. Indirectly, however, they would seem to afford a clew.

In the thermal measuring apparatus the blackened receiving surface may be supposed to absorb indiscriminately all the radiant energy falling upon it, whatever the wave-length, that is, the whole range of wave-lengths, including of course the visible rays. Thus the measurements sum up the energy in the entire spectrum, and show, as it were, the *average* darkness of the spot band when the whole spectrum is taken into account.

The results show that a spot is very much less dark measured thermally than visually. The spot band is, therefore, much darker in the visible region of the spectrum than it is in other regions; where, it would seem, it may even be *reversed*. This fact is the more striking, when we consider that in ordinary sunlight the rays which possess the maximum heating power are those about the middle of the visible spectrum, so that one would expect, *a priori*, to find a practical agreement between thermal and photometric estimates of the darkness.

Referring to Mr. Wilson's paper (*Monthly Notices*, Vol. LV, No. 8), the monthly mean values of the umbral radiation are found to vary from .35 to over .50; that of the photosphere at the center of the disk being 1.00. The photosphere radiation, however, rapidly diminishes from the center towards the limb where it becomes .45, whilst the spot radiation remains nearly constant in all positions on the disk. Thus the ratio between the radiation of the spot and that of the *neighboring* photosphere approaches unity as the spot nears the limb. The highest value of this ratio recorded by Mr. Wilson is .83, but both Langley and Frost have measured spots in which the thermal intensity even exceeded that of the surrounding photosphere.

With regard to the visible radiation of spots, it is quite obvious from ordinary telescopic observation that the umbra of a normal spot does not emit more than a very small fraction of

the light of the photosphere, even of the neighboring photosphere, when the spot is near the limb. To make sure of this point the writer has roughly estimated the relative darkness of a spot by means of an Abney photometer, so arranged as to reduce the light of any portion of the photosphere by any known amount The results obtained show that the *penumbra* of an ordinary spot is not more than one-third or one-fourth as bright as the photosphere; whilst the umbra itself is probably in most cases less than one-twentieth.

The apparatus being incapable of measuring small fractions, this latter value is probably an upper limit, the intensity may have any value less than that; many spots must indeed be at least a hundred times less bright than the neighboring photosphere at the limb, for in this position the dark umbra often presents the illusion of a piece cut out of the limb; proving that no more light comes from the spot than from the sky outside. Perhaps the average spot nucleus is not however quite so dark as this, for during partial solar eclipses spots are said to appear lighter in tint than the black disk of the Moon.

But whatever may be the true photometric value of the spot darkness the discrepancy between thermal and visual estimates is evidently very marked, and it would be of great interest to determine in what region of the spot spectrum the extra energy is to be found, which is shown by the relatively high thermal value of the radiation. Does the spot band become less dark or even reversed, in the infra-red or in the ultra-violet?

The question of the relative temperature of spots and photosphere must largely depend on the position in the spectrum of this region of maximum intensity. For suppose we admit that the whole of the Sun's interior below the photosphere behaves like an opaque solid as regards radiation. The emission spectrum will be a continuous one; but the distribution of energy in the spectrum will not be uniform. The wave-length of the rays of greatest intensity will depend on the temperature, the wave-length decreasing with increase of temperature according to a well-established law of radiating solids. Now the temperature

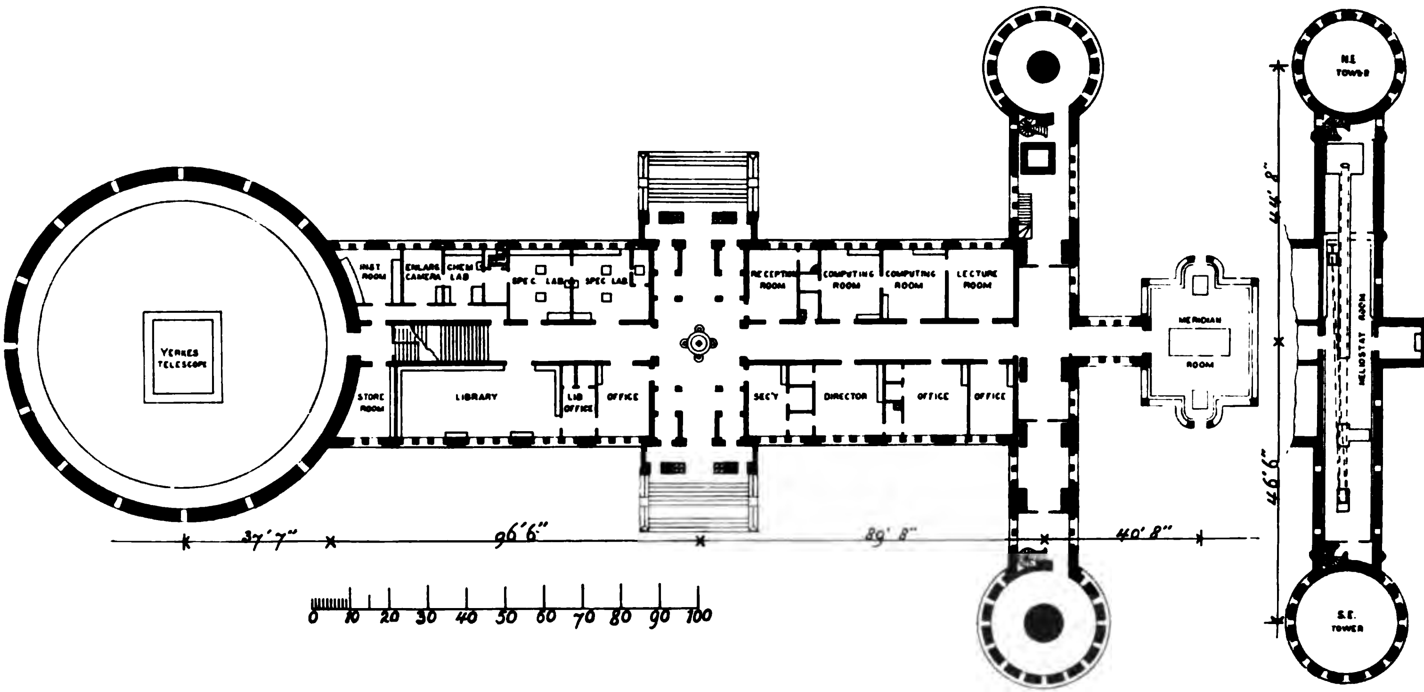
of the photosphere is such as to give, according to Langley, a maximum in the visible spectrum. But deep down in the interior the temperature must be enormously higher and the wave-length of maximum energy from that region must be shifted far into the ultra-violet.

If then in a spot we have a glimpse of the interior intensely hot regions below the photosphere we should expect to find the spot spectrum brighter (or less dark) in the ultra-violet. But if relatively cool absorbing vapors are the principal cause of spot darkness, then the maximum should be found in the infra-red; not a true emission maximum perhaps, but a part of the spectrum where the absorption has less influence than in the visible spectrum.

There is one point which would seem to be definitely settled by the thermal measures. It has been previously mentioned that the spot darkness and the general shading at the limb are different in character. This results from a comparison between the thermal and visual estimates of the darkening in the two cases. In the limb absorption the discordance between these measures is not greater than would be the case assuming it is due to a smoke-like layer which absorbs the blue rays more completely than the red and yellow, which in sunlight have the greater heating power, a feature too that is well brought out by Vogel's detailed measures made in different colors. But the spot darkness is evidently of a different character, the thermal intensity being extraordinarily high, and it is certainly not possible to explain it by assuming a greater thickness of the *same* absorbing material.

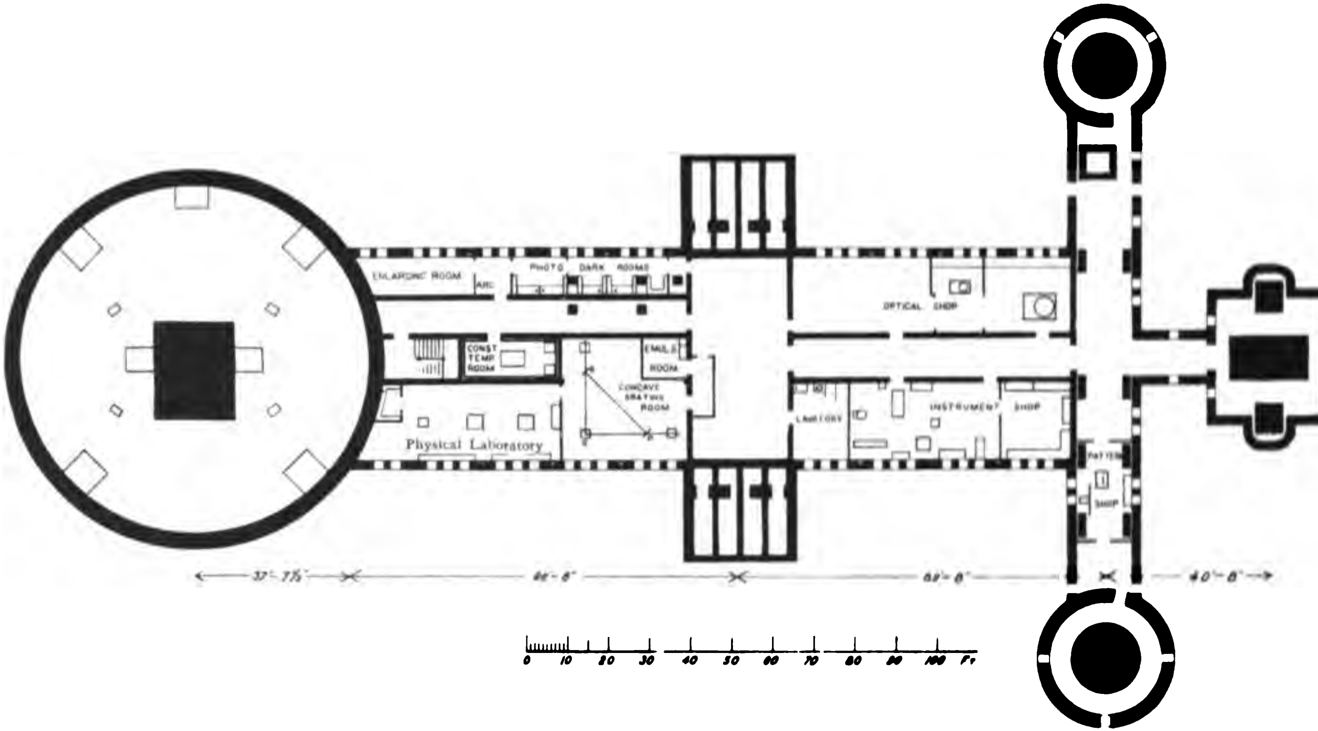
For supposing we reject Langley's and Frost's measures of abnormal spots giving a higher thermal intensity than the photosphere and consider Wilson's average result, namely .75 at .95 from the Sun's center, to be an overestimate. If a spot near the limb gave only .66 of the thermal effect of the surrounding photosphere, then, assuming the darkening of spot and limb to be only a question of degree, this would imply in the spot a 34 per cent. absorbing layer added to that which gives the general

PLATE IX.



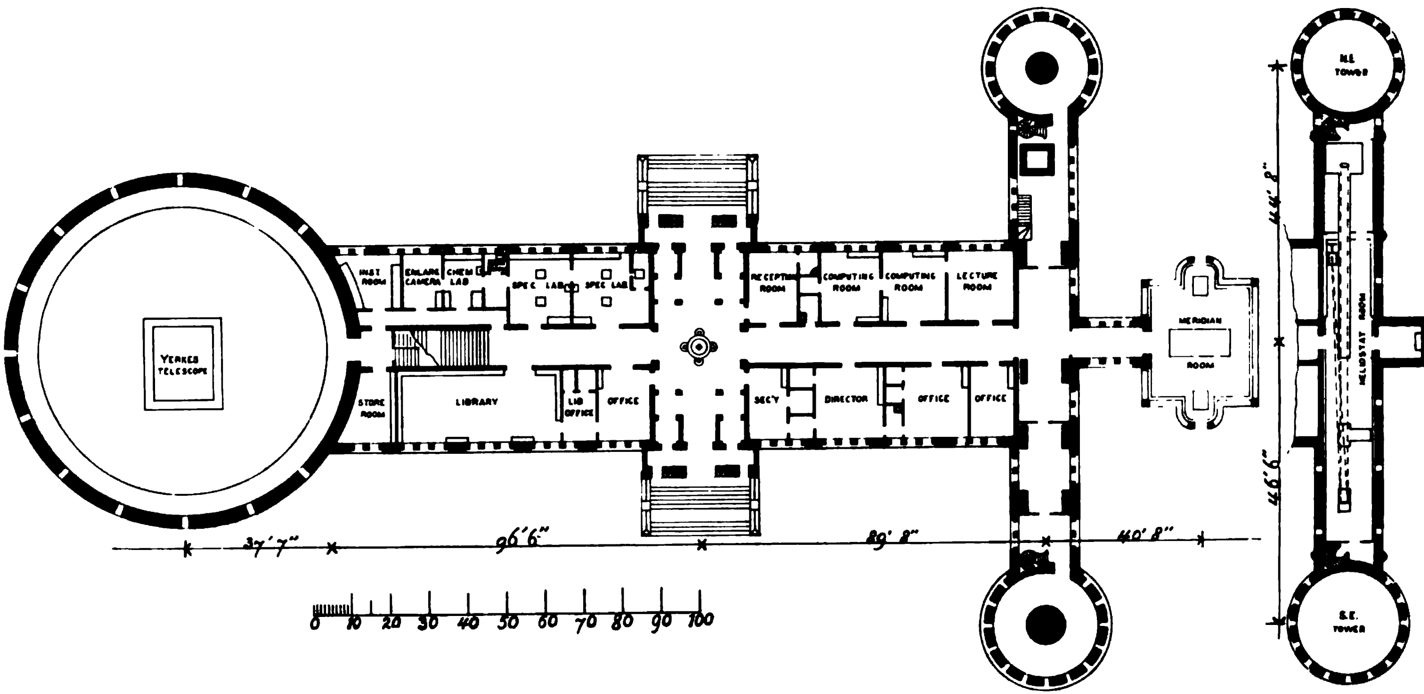
MAIN FLOOR OF THE YERKES OBSERVATORY.

PLATE X.



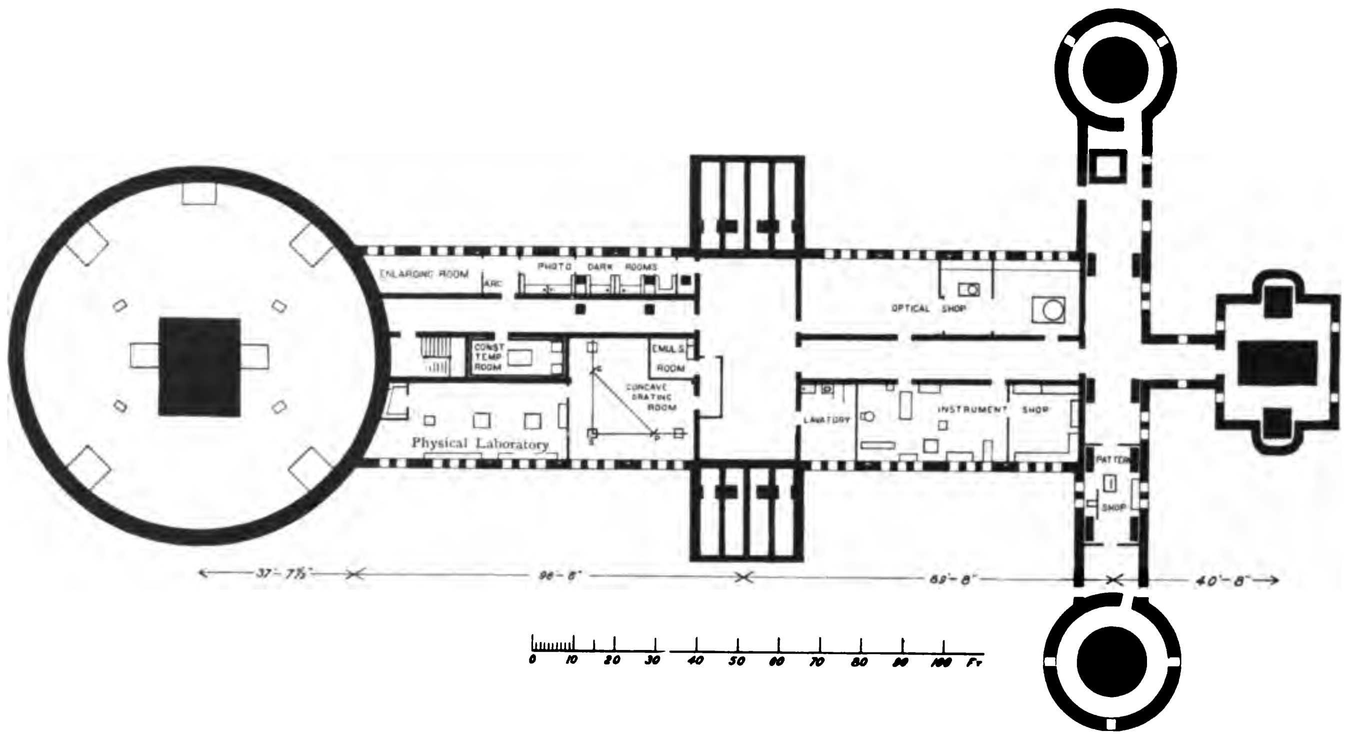
GROUND FLOOR OF THE YERKES OBSERVATORY.

PLATE IX.



MAIN FLOOR OF THE YERKES OBSERVATORY.

PLATE X.



GROUND FLOOR OF THE YERKES OBSERVATORY.

PLATE XII.

CENTRAL ROTUNDA OF THE YERKES OBSERVATORY.

ing time was spent in perfecting the plans, which were much improved as a result of further study and the adoption of important suggestions kindly offered by various men of science, to whom the thanks of the Observatory are due. They were finally completed in February 1895, and the first excavations for the building were made in April of the same year. The work of construction was carried on with various interruptions through the two succeeding years, and is now (March 1897) nearly completed. The Observatory has been occupied by the present members of the staff since October 1896.

As will be seen from an inspection of the plans (Plates IX and X) the form of the building is that of a Latin cross, with three towers and a meridian room at the extremities. This form suggested itself as one permitting the various domes to be well separated, at the same time providing sufficient space for the laboratories and other rooms between the towers. The long axis of the building lies on an east and west line, and is 326 feet in length. The large tower at the western extremity, which contains the forty-inch telescope, is ninety-two feet in diameter. This tower, together with the large telescope, dome and rising-floor, will be described in a subsequent paper. For the present attention will be confined to the other parts of the Observatory.

An examination of the accompanying illustrations will show that Mr. Cobb has worked out the design in the Romanesque style, with somewhat Saracenic details recalling the Church and Monastery of Monreale. The north and south entrances (Plate XI), which lead into the central rotunda (Plate XII), are in all respects precisely similar. The building is constructed of brown Roman brick, with terra-cotta ornaments of the same color. That portion which lies between the three towers is two stories high, with an attic above. The small towers are carried up to a greater height, in order that the large dome may not obstruct too much of the western sky in observations with the small telescopes. Balconies are provided on all the towers, with doors at the cardinal points leading out from the observing rooms. The astron-

omer is thus enabled to command an unobstructed view of the sky at any time while observing.

NORTHEAST TOWER.[1]

The northeast tower, thirty feet in diameter, is surmounted by the dome which was formerly a part of the Kenwood Observatory. This dome was built by Warner & Swasey in 1890. The running gear is on the familiar "live-ring" plan, the circular cast iron ring, from which the dome girders spring, resting on the central wheels in fourteen groups of three; the two outer wheels of each group roll on a circular iron track bolted to the stone coping which caps the brick wall of the tower. The groups of wheels are connected together with iron rods, which maintain them at constant positions in the ring. Lateral guide wheels prevent displacement in a horizontal plane. The dome is revolved by means of an endless wire rope, which passes around a ring of angle iron supported just inside of the upper track, and is brought down over guide wheels to a grooved wheel mounted in a recess cut in the south wall of the tower. This wheel is turned by means of an endless rope, hanging in the wall recess within easy reach from the floor of the observing room. The dome is covered with steel plates, bent to form and riveted to the light iron girders and to each other where they overlap. The observing slit, three feet wide, can be closed by means of a double shutter, the halves of which are moved on tracks at top and bottom by racks and pinions, controlled by a wire rope.

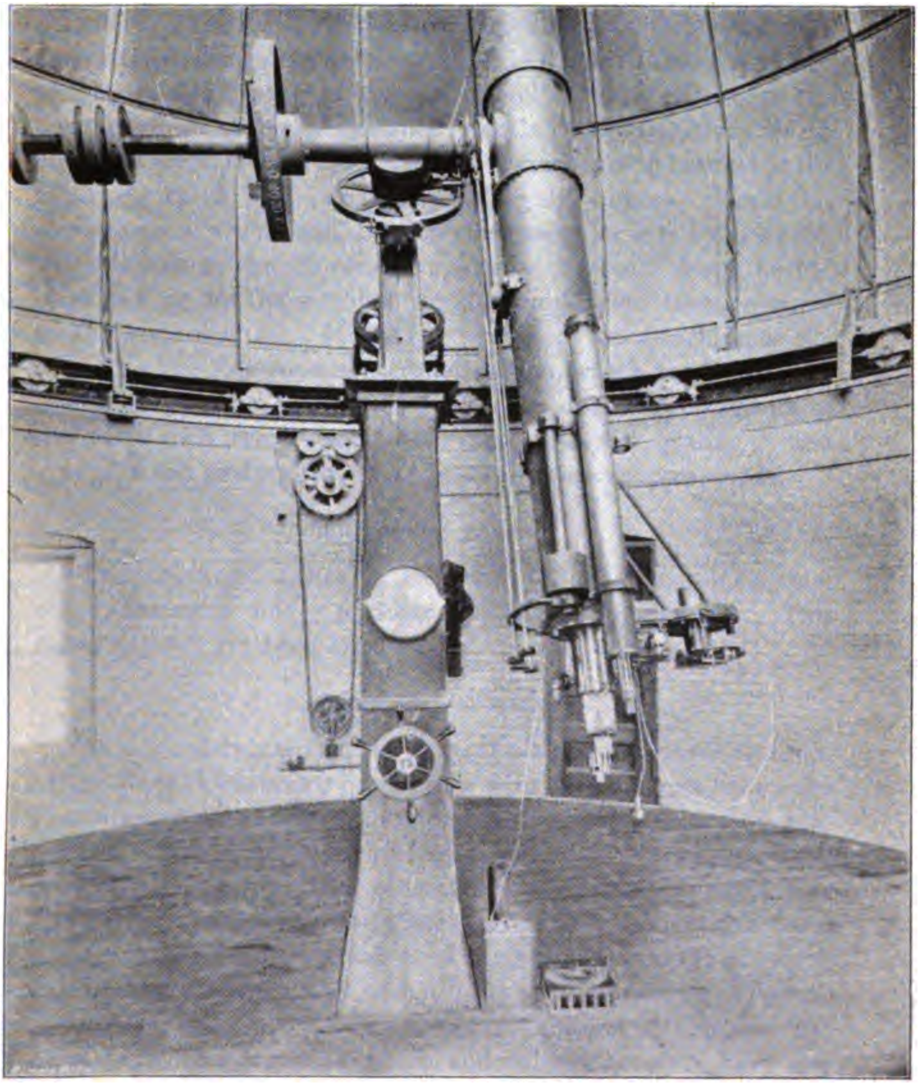
Under this dome is mounted the twelve-inch telescope which was formerly at the Kenwood Observatory in Chicago (Plate XIV). The solid brick pier which carries it is in form a frustum of a cone rising from a heavy concrete foundation. The mounting was constructed by Warner & Swasey in 1890, and served admirably for work with the large spectroheliograph of the Kenwood Observatory. It is unnecessary to more than briefly refer to it here. Two twelve-inch objectives by Brashear are provided.

[1] This tower, together with the meridian room and heliostat shutter, are shown in Plate XIII. The small dome has not yet received its final coat of paint.

PLATE XIII.

NORTHEAST WING OF THE YERKES OBSERVATORY.

PLATE XIV.



TWELVE-INCH TELESCOPE OF THE YERKES OBSERVATORY.

For observations with the micrometer only the visual objective is employed, in the usual position at the end of the tube. When it is desired to transform the instrument into a photoheliograph, the photographic objective, mounted in a short tube, is attached to a stout side bracket at the upper end of the steel tube of the telescope. A specially designed rotating shutter, driven by an electric motor, is then clamped to a corresponding bracket at the eye-end, which also carries an enlarging camera. With this arrangement, which will be described more in detail elsewhere, the solar image can be photographed in the focal plane of the objective, or, by the aid of a suitable amplifying lens, enlarged to any scale desired. Means are provided for attaching to the telescope the Kenwood spectroheliograph, which has lately been remodeled in the instrument shop; the stellar spectrograph of the forty-inch telescope; a ten-inch objective grating;[1] and several small grating, prism and direct-vision spectroscopes.

SOUTHEAST TOWER.

The southeast tower is intended for a sixteen-inch telescope, mounted under a dome thirty feet in diameter. This dome has not yet been erected.

MERIDIAN ROOM.[2]

This is constructed on the general plan of the meridian room of the Royal Observatory at Berlin, with double sheet-iron walls and intervening air space, provided with suitable means of ventilation. The room is twenty-eight feet long (exclusive of the projections containing the collimator piers), twenty-five feet wide and twenty feet high. The observing slit is three feet wide, and is covered with a counterbalanced shutter, the sections of which can be easily opened and closed by the aid of small windlasses. A massive brick pier upon a broad foundation of concrete has been built for a meridian circle, and collimator piers have also been provided. For some time to come a transit instrument

[1] See this JOURNAL, 4, 75, 1896.

[2] See Plate XIII.

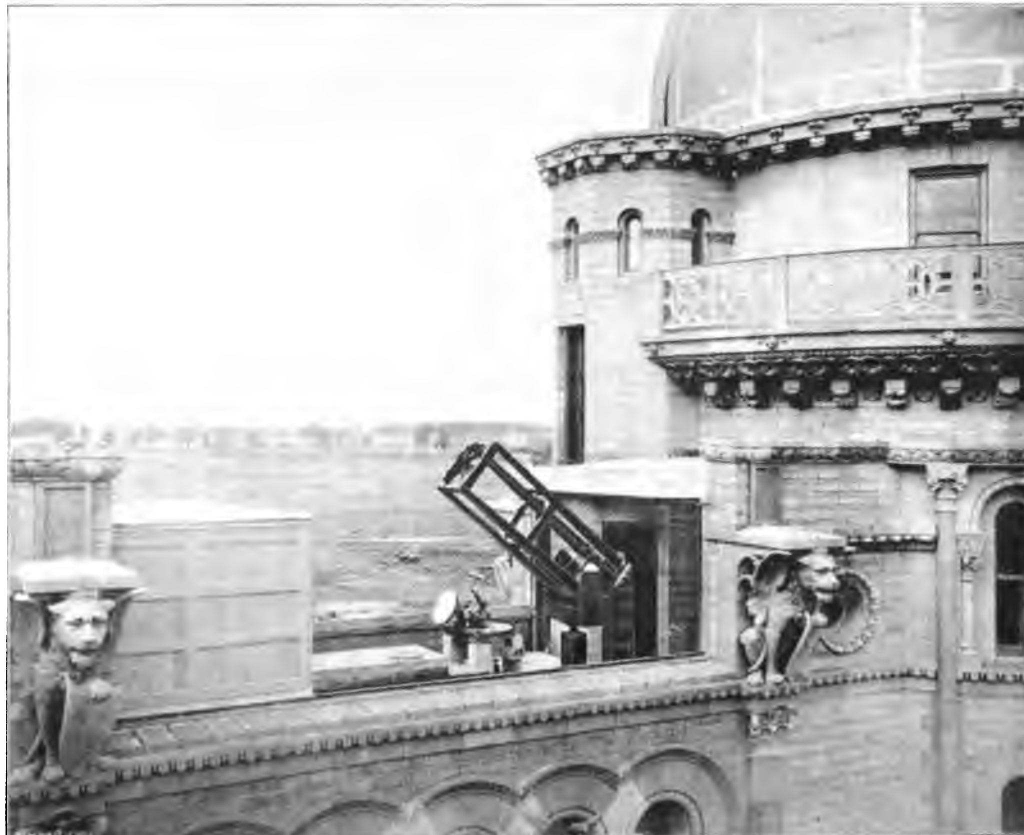
will be used in this room, on a smaller brick pier built in the center of the large pier; but it is intended that this shall subsequently give place to a large meridian circle. The architect has relieved the bareness of the outer sheet-iron walls by the use of a row of columns supporting a rich terra-cotta cornice.

HELIOSTAT ROOM.

An important feature of the Observatory is the heliostat room, which occupies the whole of that portion of the attic floor which lies between the two small towers, a space 104 feet long and twelve feet wide. Twenty-four feet from its northern extremity it is crossed by a double partition, in which are suitable openings for admitting the sunlight. The heliostat (Plate XV) stands on a large brick pier, which rises from the ground at the north end of the room. The iron roof which ordinarily covers it can be pushed away to the south, as it is mounted on wheels rolling on steel rails. It is easily moved by means of a windlass. When the roof is fully withdrawn, the heliostat mirror can receive the rays of the Sun when at its greatest southern declination. That part of the heliostat room which lies south of the double partition is shown in Plate XVI.[1] The walls and ceiling of this laboratory are of sheet-iron, separated from the brick walls and tile roof by an air space. In winter the laboratory is heated by indirect radiation from steam coils in the corners of the unfinished attic rooms. Arrangements are made by which the heated air can be thoroughly dried over unslaked lime as it enters the room, thus greatly facilitating work with rock salt prisms or lenses. The heliostat room contains four piers, the outlines of which are indicated in the plan. Each of these is supported by two separate piers, standing on opposite sides of the hall below, and bound together at the level of the first and second floors with heavy I-beams. The two northern piers are connected to each other and to the

[1] When the photograph reproduced in this plate was taken the apparatus described below had not been set up in the heliostat room. The instrument shown is a large spectroscope, temporarily mounted for the purpose of testing Abney's method of photographing the Sun in monochromatic light.

PLATE XV.



HELIOSTAT ROOM OF THE YERKES OBSERVATORY (EXTERIOR).

PLATE XVI.

HELIOSTAT ROOM OF THE YERKES OBSERVATORY (INTERIOR).

heliostat pier with three 15-inch I-beams, which form the essential part of the long pier shown in the plan. All of the piers have smooth slate tops.

The instruments outlined in the plan of the heliostat room are those used by the writer in his attempts to map the solar corona without an eclipse by the aid of a bolometer. Sunlight is reflected from the heliostat mirror to a silvered concave mirror of twenty-four inches aperture and sixty-one feet focal length, made for these experiments by Mr. G. W. Ritchey, optician of the Observatory. The mirror forms an image of the Sun nearly seven inches in diameter in a large cast-iron drum. The sunlight passes through the drum without touching it, and falls upon an amplifier, which forms an enlarged image on a screen. The bolometer is mounted in a radial slot in the drum. The inner member of the pair can be set at any desired distance from the Sun's limb and, by rotating the drum, at any position angle. The outer member is supported at right angles to the inner radial member, and its distance from the limb is constant. An assistant maintains the solar image at a fixed position on the screen by means of the slow motions of the heliostat, and rotates the drum at a signal from the observer, who watches the scale of an extremely sensitive reflecting galvanometer with a telescope. It is desired to determine whether any differences in the heat radiation of the corona can be detected at different position angles. The heliostat at present employed has been loaned to the Observatory by Professor Keeler until the one which is being constructed in our instrument shop is completed. Its mirror has an aperture of seventeen inches. The new heliostat is to have a mirror of twenty-four inches aperture, which is now being figured in our optical laboratory. The new instrument is designed to combine the functions of heliostat and coelostat, in the latter case a second fixed mirror being used with it.

A galvanometer room, provided with a heavy slate shelf to support the instrument, immediately adjoins the heliostat room on the east. The large attic rooms to the west are so arranged that they can also be used in conjunction with the heliostat room.

The entire distance (175 feet) between the heliostat room and the wall of the great tower is available for use with apparatus containing mirrors or lenses of great focal length, etc.

SPECTROSCOPIC LABORATORIES.

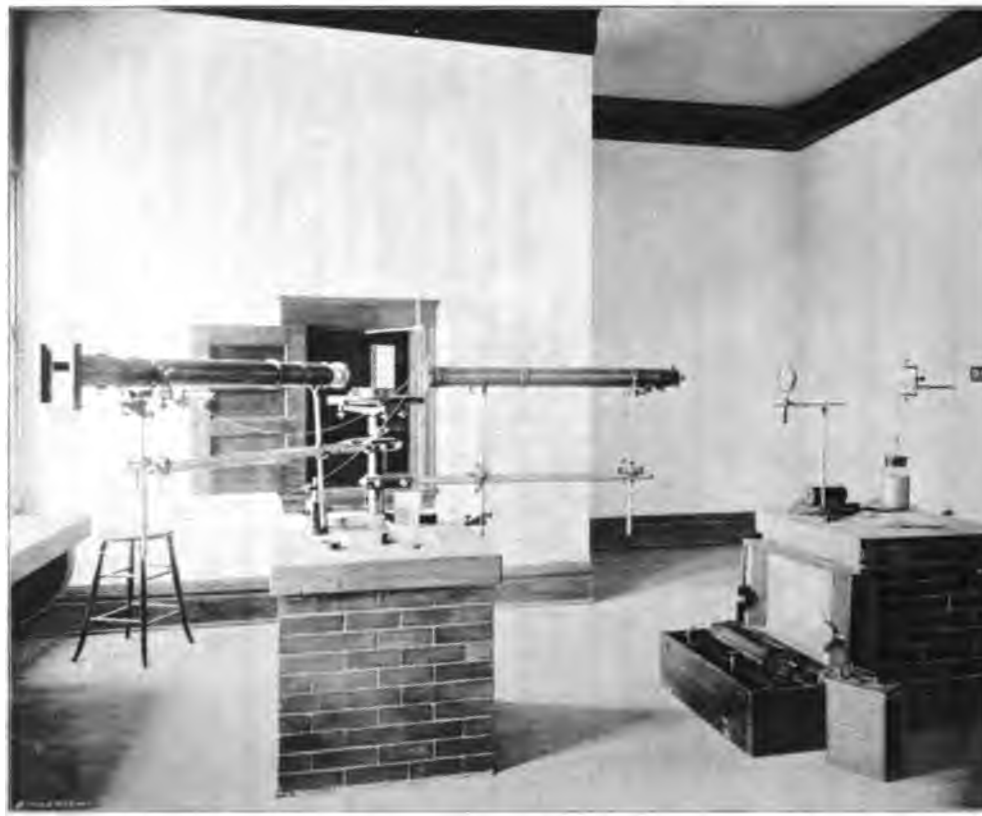
The main floor of the building is divided into offices, computing rooms, spectroscopic laboratories, chemical laboratory, instrument rooms, developing room, lecture room, library and reception room. The purpose of each room is indicated on the plan.

The spectroscopic laboratories (Plate XVII) are provided with solid brick piers on concrete foundations, which are arranged with reference to each other and to the doors and windows so that the instruments mounted upon them can be used together, or with heliostats or other apparatus mounted in the open air. In the corner of one of these laboratories is a galvanometer room containing a brick pier and heavy slate wall shelf, specially arranged for bolometric work. Two extremely sensitive reflecting galvanometers are provided. Both of the laboratories have slate shelves, four inches thick, supported by heavy slate brackets built into the outer brick wall. Sinks and running water are also provided, and the windows are fitted with rolling wood shutters, which completely exclude the light when closed. The collection of physical apparatus includes spectroscopes of various kinds, bolometers, galvanometers, interferential refractometers or "wave comparers," induction coils, special electrode holders for spectroscopic work, a Wheatstone bridge, resistance coils, and numerous prisms, gratings, achromatic objectives and mirrors of glass and speculum metal. A small photographic dark room immediately adjoining the spectroscopic laboratories is used in conjunction with them.

CHEMICAL LABORATORY.

The chemical laboratory is fitted with slate shelf, rolling window shutters, sink and running water, and a glass-covered "hood" with suitable ventilation, in which experiments with

PLATE XVII.



SPECTROSCOPIC LABORATORY OF THE YERKES OBSERVATORY.

noxious gases can be performed. It is equipped with a good assortment of chemicals, chemical glassware, balances, appliances for glass blowing, etc.

ENLARGING CAMERA.

In the room adjoining the chemical laboratory there is a large camera, specially designed for copying photographs on any desired scale of enlargement.

INSTRUMENT AND STOREROOMS.

The cases in the instrument room contain a varied collection of instruments and parts which are not needed for immediate use. The room opposite it is intended for general storage purposes; all the wood patterns made in the pattern shop are kept here after being returned from the foundry.

COMPUTING ROOMS.

The two computing rooms are fitted with heavy slate shelves to carry the measuring instruments, one of which, a Zeiss comparator, is already in use. They also contain cases designed for the preservation of the numerous photographic negatives obtained in the course of the Observatory's work. The Kenwood Observatory collection of over 3500 negatives, mainly of solar phenomena, is preserved here for convenient reference.

LIBRARY.

The library is a room 18 by 42 feet, all the available wall space of which is covered with oak bookcases, having shelves above and cupboards below. The librarian's office, provided with an iron vault for the storage of valuable papers, immediately adjoins it. The collection of books is at present far from complete, but important additions are constantly being made. The thanks of the Observatory are due for the valuable contributions which have been received from individuals and scientific institutions in all parts of the world. Some fifty different scientific periodicals are regularly received by the library. On

account of its isolated position, removed from the reference libraries of Chicago, it is of the highest importance that the collection of books be made as large and complete as possible. It goes without saying that all contributions of scientific publications have been exceedingly welcome.

The Observatory possesses a large and increasing collection of photographs, including those exhibited by the Royal Astronomical Society at the Columbian Exposition, and afterwards presented to the Observatory; a complete set of glass positives from Professor Barnard's portrait-lens photographs of the Milky Way, comets and nebulæ; and the Kenwood Observatory collection.

RECEPTION ROOM, OFFICES AND LECTURE ROOM.

The reception room for visitors opens out of the central rotunda.

Several rooms on the main floor are used as offices by members of the staff, as indicated in the plan (Plate X).

At one end of the long corrider is a lecture room, containing a large blackboard.

CONCAVE GRATING ROOM.

The floor below is reached by stairs at both ends of the building. The eastern half of this lower story is devoted to the optical laboratory and the instrument and pattern shops, which, with the power house, will be described in another article. The western half contains the concave grating room, physical laboratory, constant temperature room, emulsion room, enlarging room, and photographic dark rooms. The concave grating room is specially designed to contain a concave grating of twenty-one feet radius, mounted in the ordinary manner. The instruments at present used are a four-inch concave grating of ten feet focus, and a smaller one of six feet focus, from the Kenwood Observatory collection. The three brick piers, with slate tops, which carry the mounting, are shown in the plan (Plate XI). The slit is at *S*, the grating at *G*, and the plate-

holder or eyepiece at *P*. Sunlight is reflected into the room from the mirror of a heliostat placed outside the window, a lens being interposed to form an image of the Sun on the slit. An image of an electric arc or other light source may also be formed on the slit, either by placing the light in the direction from which the sunlight comes, or to one side, a reflecting prism being employed in the latter case. A window has been cut in the partition which separates the concave grating room from the adjoining physical laboratory, and the centers of the piers in this latter room are in line with the rail on which the plate carriage moves. Thus any desired apparatus can be used in conjunction with the concave grating. Both rooms have rolling wood shutters, which effectually exclude the light. The physical laboratory is also provided with heavy slate shelves and an instrument case. The piers in this room have been found to be extremely steady, the most sensitive galvanometer showing no signs of vibration due to the machinery in the instrument shop. A variety of minor apparatus, consisting of a large Apps induction coil, mercury pump, oxy-hydrogen burners, arc lamp, special electrode holders for spark spectra, Geissler tubes, etc., from the Kenwood Observatory collection, is available for use with the concave grating, or in the other laboratories. The concave grating room is reached from the central hall through a passageway having both outer and inner doors. Thus the room may be entered at any time during a long exposure without danger of admitting light and fogging the plate.

EMULSION ROOM.

In one corner of the concave grating room is the "emulsion room," fitted with sink and running water for photographic purposes. The walls and ceiling are painted black, and can be sponged perfectly free from dust when photographic preparations requiring very careful treatment are to be made. This room can also be entered from the central hall without danger of admitting light.

PHOTOGRAPHIC DARK ROOM.

The large photographic dark room is on the north side of the building, opening into the central hall through a double door. It is divided into three stalls, two for developing and one without sink or water for use in changing plates. Each stall is supplied with numerous shelves, and each has a ventilated recess in the wall fitted with a swinging door glazed with red glass, designed to contain the electric or oil lamp used for illumination. Immediately adjoining the developing room is a room for fixing and washing plates. Two sinks are provided, one to contain "hypo" tanks for plates of various sizes, the other for the washing tanks. The outside windows of this room are glazed with red glass, and admit much more light than would be safe in a developing room, but not too much to affect the plates before and during their immersion in the hyposulphite bath.

ENLARGING ROOM.

The small room next to this contains a photo-engraver's arc-lamp, for enlarging and copying photographs by electric light. A pair of large condensers are fitted into an opening in the partition, and within there is a frame for supporting the negative. Beyond this is the enlarging lens, which projects the image upon a screen mounted on rollers, which can be set at any desired distance (up to twenty-four feet). All of these rooms are provided with rolling wood shutters, which can be instantly opened or closed. The walls and ceilings are painted dark red. The developing and washing rooms have cement floors.

CONSTANT TEMPERATURE ROOM.

On the opposite side of the long hall is the constant temperature room, which has double walls with intervening air space and double doors. This room contains two clock piers, and a brick pier with large slate top for experimental work which must be carried on under conditions of constant temperature. The only astronomical clock yet in place is a fine Howard clock from the Kenwood Observatory.

All of the rooms of the Observatory are connected with boxes running along the ceiling of the lower story, through which electric wires can be drawn. The building is lighted throughout by incandescent electric lamps, and heated by steam. A system of telephones places the Director's office in communication with the three domes and the power house. But little wood was used in constructing the Observatory, the walls being of brick and terra-cotta on concrete foundations, the partitions of hollow tile, and the floors and roof of tile supported by steel I-beams. The floor of the long hall in the main story is of marble mosaic, and the walls are wainscoted with marble. The offices and laboratories have maple floors, and oak is used throughout the building for the doors and other wood finish.

PORTRAIT LENS AND COMET SEEKER.

A circular building ten feet in diameter, surmounted by a light steel dome having a very broad slit, has been erected on the Observatory grounds about 300 feet southwest of the great tower. This will contain an equatorially mounted portrait lens for photographing comets, the Milky Way, nebulæ, etc. A comet seeker will be established at no great distance from this dome.

REFLECTING TELESCOPES.

The Observatory will have the use of two large silvered glass reflecting telescopes. One of these, of twenty-four inches aperture and eight feet focal length, which was made by Mr. Ritchey for photographic work, is already employed for visual observations, on a temporary mounting in the heliostat room. The sixty-inch mirror of the other instrument, which is to be mounted as an *equatorial coudé* for astrophysical investigations, will soon be figured in the optical laboratory.

YERKES OBSERVATORY,
March 1897.

(*To be continued.*)

THERMAL MEASUREMENTS WITH THE BOLOMETER BY THE ZERO METHOD.

By F. L. O. WADSWORTH.[1]

IN the May number of the *Annales de Chimie et de Physique*,[2] in an article entitled "Sur le Bolometer," M. Crova describes what may perhaps be termed a zero method of using the bolometer, for which he claims a number of advantages. The arrangement which he proposes is only a modification of the well-known form of slide wire bridge which is now so universally used in the exact measurement and comparison of standard resistance coils, and the credit for any novelty which there may be in its application to the purpose for which he designs it belongs, I think, to Dr. Hallock, my predecessor in the Observatory, who first used it in the winter or early spring of 1892, over a year before the publication of M. Crova's paper.

When I was placed in charge of the work at the Observatory in October of the same year, I modified the existing arrangement, with a view to securing a more sensitive and reliable action, by substituting for the single balancing wire of copper two much larger wires of platinoid, which were stretched side by side about 1^{cm} apart, as shown at $a\,b$, $a'b'$, Fig. 1. The inner one was connected to the terminals of the bridge ab; the other one to one of the battery terminals, and a sliding clamp c used to connect the two. All movable wires were thus avoided and a smoother motion and better contact secured for the balancing

[1] Then Senior Assistant (in charge) of the Astrophysical Observatory, Washington, D. C.

[2] The main part of this paper was written, as may be seen by the appended date, over three years ago, or only a few months after M. Crova's article appeared. On account of pressure of other work it was laid aside and forgotten, until in looking over my papers a few days ago, I came across it. Although it is now considerably out of date as a reply to M. Crova's article I have been requested to publish it as it stands, although I hope before long to treat the whole subject of bolometric work in a more complete and satisfactory manner.

clamp. The wires were about 2^{mm} in diameter, and the change of resistance per millimeter of length was therefore

$$R = s\frac{l}{\pi r^2} = \frac{0.33 \times 10^{-5}}{0.0314} = \text{only } 0.0001 \text{ ohm.}$$

I soon found, however, that even this was far too large a rate of change for exact measurements, for with the new galvanometer

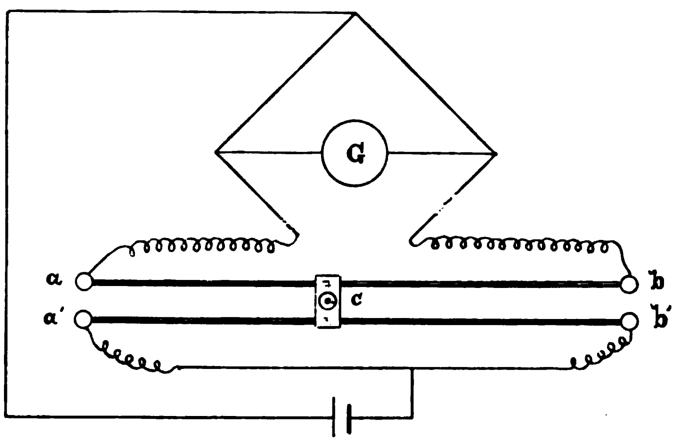


Fig. 1

which had in the meantime been constructed for the work,[1] the bridge system was so delicate that a movement of less than $0^{mm}.1$ caused a galvanometer deflection of more than a hundred divisions on the scale, and since the deflection could be read to a tenth of a division, it was at once evident that with this arrangement the accuracy of the zero method, even supposing that the position of the slider could be determined to $0^{mm}.01$, would only be about $\frac{1}{100}$ as great as the direct reading of deflections. In order to attain the same degree of accuracy, a balancing wire would have to be used having a cross section at least one hundred and probably one thousand times as great (since movements smaller than $\frac{1}{10}^{mm}$ can hardly be relied upon with any form of sliding contact). This would

[1] A description of this instrument appeared in the *Phil. Mag.* for December 1894.

have meant a wire over 60^{mm} in diameter, which was of course quite out of the question as a practical arrangement. This form of balance was therefore discarded and the one shown in Fig. 2 was, after some study, adopted in its place. In this we have the same two platinoid wires, ab, $a'b'$; the terminals a b being connected to the bridge terminals as before, and the terminals $a'b'$ of the second wire being now connected by means of flexible copper conductors of small resistance to two movable clamps m, n, on the first wire. A third clamp o connected to the battery terminal slides upon the wire $a'b'$ The theory of this arrangement (which is simply a modified form of shunt), is as follows:

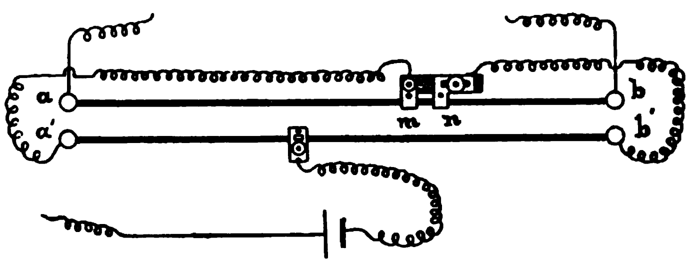


Fig. 2

Let x (Fig. 2) be the resistance of that portion of the wire ab between the two clamps m n; p the resistance of that portion of the wire $a'b'$ from o to a'; q that of the wire from o to b', and R and R' the resistance from m to a and n to b respectively.

Then we have:

Total resistance o to a (left hand bridge terminal),

$$R_{oa} = R + \frac{1}{\frac{1}{p} + \frac{1}{q+x}} = R + \frac{p(q+x)}{p+q+x},$$

and total resistance o to b (right hand bridge terminal),

$$R_{ob} = R' + \frac{q(p+x)}{p+q+x}.$$

But R and R' may be considered simply as forming parts of

the bridge arms P, Q; and hence, when the bridge is in balance, $P + R = Q + R'$, and, therefore,

$$R_{oa} - R_{ob} = \frac{(p - q)\, x}{p + q + x}.$$

Let y be the distance of the clamp o from the center of the wire, and let l be the whole length of the wire $a'\, b'$. Then, if r_o is the resistance per unit length,

$$r_o y = p - q \quad \text{and} \quad r_o l = p + q,$$

$$\therefore\ R_{oa} - R_{ob} = r_o y \frac{x}{r_o l + x}.$$

In the previous arrangement the change in resistance between the two arms of the bridge produced by moving the balancing clamp a distance y was simply $2\, r_o y$.

With the new arrangement the change in resistance for a given motion y has, therefore, been reduced in the ratio

$$\frac{x}{2\,(r_o l + x)}, \quad \text{or nearly} \quad \frac{x}{2\, r_o l},$$

if x is small as compared to l.

The second wire evidently plays the same part with respect to the first that the eyepiece of a telescope performs for the objective. The eyepiece magnifies the image formed by the objective in the ratio $\frac{f}{f'}$, while the wire $a'b'$ magnifies the motion of o in the ratio $2\frac{r_o l}{x} = 2\frac{l}{\overline{mn}}$, if the wires $a\,b$ and $a'b'$ have the same resistance per unit length. In the actual arrangement l was about 40^{cm}, and the distance $\overline{mn}$ was 1^{mm}. The magnification was, therefore, 800, or the system was equivalent to a single balancing wire having a cross section 800 times as great as that of the wires used. By making x still smaller, either by decreasing the distance $\overline{mn}$ or increasing the size of the wire ab, still greater magnification may, of course, be easily obtained, and the errors, due to inequalities in the size of the wire $a'b'$ and uncertainty as to the exact point of contact of the balancing clamp o with the latter, made as small as we choose. This arrangement, therefore, both on account of this greater sensitiveness and also on account of its greater compactness for

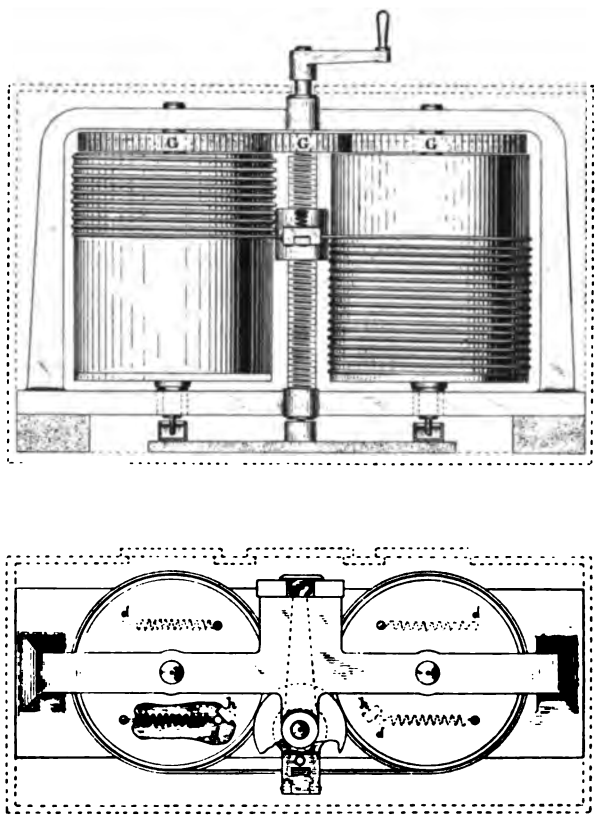
a given range of resistance, is far better adapted to accurate measurements by the zero method than the usual single-slide wire, and since, as we have just seen, the change of resistance is directly proportional to the linear movement of the balancing clamp or slider c, it is equally as convenient to use.

When the magnification is high the rate of variation of resistance along the wire $a'b'$ is, of course, low, and in order to obtain a considerable range the latter would have to be of considerable length.[1] In this case a very compact and convenient mounting for the second wire $a'b'$ is a modification of Thomson's drum rheostat which I have designed for this work and which is shown in plan and side elevation in Plate XVIII. The wire is wound, as shown in the plate, on two accurately turned ebonite cylinders,[2] which are geared together at one end by means of spur wheels G, G, G, so as to turn in the same direction with the same angular velocity. The ends of the wires are permanently attached to a heavy brass plate at the lower end of the cylinders and the sliding clamp, o, is carried on a copper screw s, which is driven by means of the intermediate gear G at a speed about twice that of the drums. The pitch of this screw is such that the clamp, o (which serves also as a guide for the wire, as it winds from one cylinder onto the other), moves a distance equal to about the diameter of the wire for every revolution of the screw. Continuous connection is made with the two plates with which the ends of the wire are connected by means of two attached copper wires which revolve in mercury cups, connected to the clamps m, n of the bridge system; and

[1] So far as a range of resistance is concerned, this is furnished by a movement of the two clamps m, n, either independently or together along the wire ab. But the accuracy of the determination of the change of resistance is in this case limited, just as in the case of the single-slide wire arrangement, by the accuracy of the determination of the position of the clamps m, n. It is well to have these movable in order to effect a preliminary adjustment of the bridge arms to approximate equality, and for this purpose it is convenient to have them so mounted on a single block of hard rubber (Fig. 2), that while they may be shifted slightly with respect to each other (in order to change the magnification if desired), they may usually be moved together as a unit along the wire ab.

[2] Brass covered with a thin sheet of ebonite would be better.

PLATE XVIII.



DRUM RHEOSTAT FOR BOLOMETRIC MEASUREMENTS.

connection is similarly established between the clamp *c* and the battery circuit through the copper screw *s*, the lower end of which revolves in a third mercury cup.[1]

The position of the slider with reference to one end or the center of the wire (or with reference to any intermediate point which may correspond to the initial zero of the bridge), is determined by means of a scale engraved on the guide in which the tail piece of the clamp, *o*, slides, and a graduated head on one of the drums; the former giving the whole number of turns and the latter the fractions of a turn of the drums; from which, when we know the diameter of the cylinders and the pitch of *s*, the length of wire wound from one to the other may be at once determined. In order to keep the wire under a constant tension and thus make the winding as smooth and regular as possible, the large gears are left loose on the shafts of the drums and are only connected with the latter by means of strong spiral springs, as shown in Plate XVIII.[2] In order to keep the wire at a constant temperature the whole arrangement may be immersed in a bath of oil, but it usually suffices to simply enclose it in a wooden box (as shown by the dotted lines), provided with a glass window through which the position of the slider may be read on the scale and graduated head. The minor details of construction may be easily understood from an inspection of the drawings themselves.

As regards the comparative advantages of the two methods (the deflection and the zero method) of measurement it is possible to institute only a very general comparison. The process of making thermal measurements with the bolometer is, it is true, only a process of making a series of measurements of

[1] To avoid any connection between the two ends of the wire the bearings in which the drum axles turn are mounted in rubber bushings and the gear on the screw is made of rawhide or vulcanite fiber.

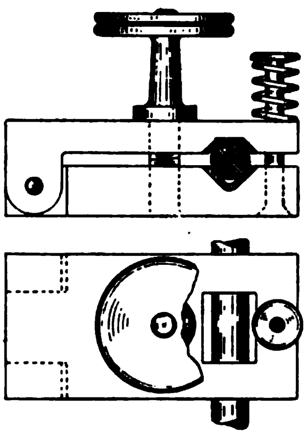
[2] A more accurate method of determining the position of the slider on the wire, which has recently suggested itself, is to make the latter in the form of a thick tape which is graduated on its upper surface. This would entirely avoid any errors due to irregularities in the winding or in the surface of the drum, or to changes in the tension of the wire.

resistance, and from that point of view alone the zero method would have the same advantages which attend its use in the accurate comparison of resistance coils by the slide wire bridge. The zero method has also a much wider range than the method of deflections, and if we wished to directly compare the radiation from two sources of energy, one of which is several thousand times as intense as the other, the former would be much more direct and perhaps also more accurate than the latter, which would necessarily involve the use of shunts.

On the other hand the method of deflections is much more expeditious and more readily admits of a continuous registration of the variations in the intensity of radiation falling on the bolometer strip, if these variations are not too large. It has also the advantage of involving no disturbance of contacts in any part of the bridge circuit, an advantage of so much importance when the bolometer is in its highest state of sensitiveness, that it practically excludes the employment of the zero method for accurate measurements of very feeble radiations. The reason for this is not at first apparent, for since the only sliding contact is at one of the battery terminals it would seem at first sight that any slight variation of resistance at that point would affect both arms of the bridge alike, and leave its balance undisturbed. But observation shows that any such variation (even when very small indeed) does affect the balance of the bridge very considerably, and the reason for this is that it causes a minute change of resistance and therefore a minute change of current in the battery circuit. In order to avoid this effect as far as possible many forms of sliding contact were tried. What is needed is something that can be easily slid along the wire, and at the same time can always be relied upon to maintain good contact. A sliding mercury contact is one of the first things that suggest themselves for this purpose, but none have been found that can be relied upon for any length of time. The best arrangement so far found is one similar to that shown in Fig. 3. It consists simply of two brass plates hinged together at the back and held together at the front

by a strong spiral spring. The wire lies in two V grooves lined with platinum, and cut away in the center in order to insure two perfectly definite points of contact at the ends. A screw is added to secure the clamp in place at any desired point on the wire. The clamp through which the wire passes in the case of the drum mounting already described is exactly similar in character.

Fig. 8



The effect of a small change of current in the bridge has not been considered, nor as far as I know even mentioned as a source of difficulty by those writers who have described most fully the manipulation of the bolometer, and I may therefore consider it, together with some other points of importance, more in detail in a subsequent paper.

Suffice it to say here, that in some of the earlier forms of bolometer (I have in mind particularly those designed and used by Mr. Langley in his thermal measurements in the infra-red spectrum at Allegheny, 1881–6),[1] a variation in the strength of the battery current of only one part in 1000 ($\frac{1}{10}$ of 1 per cent.), would produce a difference in the temperature of the two strips

[1] Described by Mr. Langley in the *Proceedings of the American Academy of Arts and Sciences*, 16, 342, 1881.

of considerably over a tenth of a degree, or a difference a thousand times as great as that produced by the feeblest radiations which could be measured. This relatively enormous change in this case is due in large part to some radical errors in the design of these bolometers. With a properly designed and well constructed instrument this effect is reduced at least a hundred times, but it remains even then relatively large to the effects which are to be measured, and becomes of greater and greater importance as the delicacy of the whole system is increased. It alone is sufficient to account for nearly all the phenomena of bolometric "drift" which has been heretofore attributed to gradual changes in the temperature of the surroundings, or to changes in the amount of energy falling on the bolometer strip caused by changes in the atmospheric absorption.[1]

SMITHSONIAN ASTROPHYSICAL OBSERVATORY,
Washington, D. C., July 1893.

[1] That this latter explanation at least is very far from the true one is seen readily enough from the fact that the drift observed is often many times as great as could possibly be occasioned by the cause in question; many times greater, in fact, than that produced by changes in the radiation equal to the total amount falling on the bolometer strip.

Minor Contributions and Notes.

NOTE ON PROFESSOR CAMPBELL'S OBSERVATIONS OF NOVA AURIGAE.[1]

In *A. N.*, No. 3238, 135, 386–390, I have given a long series of measures of the position of *Nova Aurigae* with reference to two comparison stars, *E* and *F*. These measures were made at Mt. Hamilton with the thirty-six-inch to detect parallax or motion, neither of which were shown to exist. In this paper I have the following note on the appearance of the *Nova*, which, from his remarks above, Professor Campbell seems to have overlooked.

"Much has been said of late in regard to the nebulosity of the *Nova*. Dr. Huggins, Dr. Vogel, and Mr. Newall think it is simply a telescopic effect.

"For my own part I am anxious to do all I can to settle the question, as I was instrumental in getting it started. I will therefore state all I have learned about this nebulosity. I have no theory whatever to defend, and simply wish the truth to be known, and if my observations can be of any service in getting at the true condition of this wonderful object I shall be satisfied.

"When I examined this star on August 19, 1892, it appeared to me to be densely nebulous, and since then it has not appreciably changed.

"The comparison star *F* is yellowish, while the *Nova* is bluish white. These two extremes of the spectrum make quite a difference in the focus for the two objects, as has been pointed out by Mr. Newall in his experience with the twenty-five-inch at Cambridge. This amounts to $\frac{1}{16}$ of an inch with the thirty-six-inch, and the *Nova* comes to a focus outside of that for *F*. When the *Nova* is in the best possible focus it is hazy and surrounded for 5″ or 6″ with a decided nebulosity. Now when *F* is in focus there is no such glow about it, nor is there about any of the other stars near.

"How much of this nebulosity is due to the peculiarity of the spectrum of the *Nova* I am not able to tell. But from my experience with nebulæ I would unhesitatingly say that the *Nova* is distinctly and

[1] See p. 240

unquestionably nebulous. It seems to me that Dr. Huggins' examination of this object with a large reflector—if he uses a high enough power—is the fairer test, as no peculiarity of refraction would enter into the formation of its image. To me the star is nebulous when in perfect focus both with the thirty-six-inch and the twelve-inch. As I have said, whether this is an effect of some peculiarity of its spectrum or not I am unable to tell.

"The following will cover the apparent phenomena: When the *Nova* is in perfect focus it is hazy or woolly, the image fading into a nebulous glow some 5″ or 6″ in diameter. Under this condition *F* is surrounded by a disk of light several seconds in diameter and slightly yellowish. When *F* is in perfect focus it is clear cut and sharp, with no traces of a nebulous glow about it; the *Nova* is then surrounded by a similar mass of light to that previously shown by *F*, except that it is whitish.

"When I examined the *Nova* on August 19, 1892, I stated that it was apparently nebulous before I knew of any spectroscopic or other observations indicating a nebulous condition."

MT. HAMILTON, April 9, 1894.

I have nothing to add to or to subtract from the above statement, further than to say that on the morning of August 20, 1892, both Professor Campbell and myself independently announced to Professor Holden that this star was nebulous, from the previous night's observations, one with the spectroscope and the other visually, and each without knowing of the work of the other. Indeed I knew nothing of the spectroscopic observations until the evening of August 20.

A continuation of my measures of the position of Nova Aurigae, referred to above, will be found in *A. N.*, No. 3279, 137, 233.

E. E. BARNARD.

YERKES OBSERVATORY,
March 21, 1897.

ERRATA.

The following corrections should be made in Professor Harzer's article in the January 1897 number of this JOURNAL:

Page 36, second line from the top, for *vigor* read *rigor*.

Page 37, for Δ read 1 (three times).

DR. ARENDT'S SPECTROSCOPIC INVESTIGATION OF THE VARIATION OF AQUEOUS VAPOR IN THE ATMOSPHERE.[1]

IN the review by Professor E. B. Frost in the February number of the ASTROPHYSICAL JOURNAL, of Dr. Arendt's paper on the spectroscopic observation of variations of the amount of aqueous vapor in the atmosphere, there is a very serious error which should be corrected.

The statement is made that the increase in intensity of atmospheric lines in the spectrum is proportional to the increase in path. Probably what is meant is that the increase in intensity is as the increase in amount of atmosphere traversed by sunlight. But this statement not only supposes that the character of the distribution of aqueous vapor in the Earth's atmosphere is the same as that of the other gases, which is very far from being true, but that the increase in intensity of absorption should be as the increase in the amount of the absorbing gas traversed by sunlight, which is directly contrary to the law of absorption in which the absorption factor enters as an exponential term.

In my paper[2] it was thought best not to enter into these matters to any great extent, but this subject was carefully investigated and the value of the absorption factor for oxygen lines was determined, and the theoretical values of the intensity of oxygen lines at different altitudes of the Sun were calculated and compared with the results of observation, and they were found to agree within the limits of errors of observation.

In the case of water-vapor, the absorption factor was determined only approximately by an indirect method which consisted in plotting together the intensities (reduced to the standard condition of the Sun in the zenith), for a large number of days, when complete series of observations were secured, and the absolute humidity for those days. The result was not a straight line but somewhat of a curve, as it should be according to absorption laws; but any such determination can be but unsatisfactory because of the probable difference in the character of the distribution of aqueous vapor in the atmosphere during warm and cold weather.

[1] "Die Schwankungen im Wasserdampfgehalte der Atmosphäre auf Grund spectroskopischer Untersuchungen." Th. Arendt, *Wied. Ann.* 58, 171–204, 1896.

[2] *Ap. J.* 4, 324, 1896.

It was also shown by the investigation that if the absorption be supposed to increase proportionately with the amount of vapor traversed, no possible method of distribution of aqueous vapor in the atmosphere will give results agreeing with those of observation, while if the value of the absorption factor found be taken, then rational methods of distribution of aqueous vapor in the atmosphere will give results agreeing fairly well with observations. But the character of the distribution not only varies very greatly with the season, but is vastly different from that of the oxygen and nitrogen in the atmosphere, except during the prevalence of cold waves, when there is considerable resemblance. As this work was very laborious, and it was hoped before long to obtain special observations which would give accurate data for determining the value of the absorption factor for aqueous vapor free from the uncertainties of indirect methods, these comparisons were only carried out far enough to get a good idea of the facts in the case.

Professor Frost is mistaken in supposing that Dr. Arendt's method of comparing atmospheric and solar lines was different from mine. The method which he used (in 1895) was used by me during 1892 and 1893, and the method of comparison, together with a description of a photographic scale for determining the relative intensity of the solar lines used for comparison, and some of the results of observation obtained, were described in a paper read by Dr. J. S. Ames at the Congress of Astronomy and Astrophysics in Chicago, August 1893, and published in *Astronomy and Astrophysics* for November 1893.

The essential difference in the methods pursued by Dr. Arendt and myself were that I carefully determined the intensities of the solar lines used for comparisons by the aid of a photographic scale, the lines of which varied uniformly in intensity according to an exact law, and which closely resembled in appearance the spectrum lines which were measured.

In observations of the oxygen lines comparisons were made with selected solar lines (the intensities of which had been determined by the photographic scale) and also directly in the spectroscope with the lines of the scale, and the two methods gave concordant results. Some observations of the water-vapor lines have also been made in the same way, and as a result of comparison of the two methods, I can say that a direct comparison with the lines of the scale gives far more accurate results and is much more simple and satisfactory in every way. However, measurements of three or four solar lines of different intensity

should be made at the same time to obtain the slight corrections which are necessary where the width of the slit does not remain constant.

Had all of my observations been made in this direct way, greater accuracy would have been secured and an enormous amount of time and labor in the work of reduction would have been saved.

For determining the intensity of the comparison solar lines, Dr. Arendt's method of intensity steps gauged by the eye alone is certainly far from satisfactory where much accuracy is desired, as it is little better than guess-work, for the eye is quite unreliable for estimating how great differences in intensity are, though quite accurate for determining equality.

The principal reason why a spectroscope is not to be recommended as an addition to the instrumental equipment of all meteorological stations for prediction purposes, is that a set of observations, from sunrise to noon or from noon to sunset, is necessary for determining the data desired; or if observations are confined to those made near the meridian, they may not be strictly comparable with the meteorological observations which are made in the morning and evening, and in point of time are not available for prediction purposes. At selected stations, however, meridian observations might be of value.

However, for purposes of studying the distribution and amount of aqueous vapor in the atmosphere, I believe the spectroscope is capable of giving much valuable and readily secured data, after the value for the absorption factor of aqueous vapor has been determined. Plans have been made which it is hoped will lead to the securing of this data before very long.

LEWIS E. JEWELL.

JOHNS HOPKINS UNIVERSITY,
March 10, 1897.

Reviews.

PHYSICAL PROPERTIES OF X-RAYS.

ALTHOUGH many new properties of these rays have been discovered during the past year, as yet no crucial experiment has been brought forward to decide whether they are longitudinal or transverse waves, or streams of material particles like the cathode rays. That they are streams of material particles is, however, unlikely in view of the experiments of Minchin and Threlfall. The ulcerations of the skin and injurious effects on the joints, which have resulted, in some instances, from long continued exposure to the Röntgen rays, have probably no connection with these rays, but may be due to the cathode rays outside the tube. The possibilities of longitudinal vibrations in the ether have been discussed by Professor J. J. Thomson (*Proc. Phil. Soc., Cambridge*, Vol. IX, Part II) in which he shows that when convection currents exist, the condition for the vanishing of the longitudinal wave is not satisfied, and in this case we may have longitudinal waves. These conditions exist in a vacuum tube, and would even exist in solid dielectric media, provided each molecule were made up of a pair of oppositely charged atoms. The necessary condition for the production of these waves being (1) that we should have means of producing waves whose length is comparable with molecular distances and (2) that we should be able to set the ether in motion. Both convection and longitudinal dielectric waves require for their propagation the presence of matter-carrying charges, for on Maxwell's electromagnetic theory the longitudinal wave could not be propagated in ether free from matter.

On the other hand, Professor Thomson (B. A. Address, *Nature*, September 17, 1896) has called attention to the fact that nearly every property of these rays is possessed by some form or other of light. For instance, many of the properties of these rays are possessed by a radiation emitted by the uranium salts and other fluorescent substances. This new radiation, which was recently discovered by Becquerel, is undoubtedly light, as it can be polarized. So far, the two essential properties of light waves, refraction and polarization, seem

to be absent from the Röntgen rays; but the absence of refraction is not uncommon even in ordinary light. As we know from the experiments of Kundt, Pflüger, and others, certain waves can pass through gold, silver, copper, and the aniline dyes without experiencing any refraction, while other waves are bent in the wrong direction. Professor Thomson also calls attention to the fact that according to our theories of dispersion we should not expect to find any refraction if the frequency of these waves is very great. Thus, on the Helmholtz dispersion theory, which is based on the assumption that a molecule of the refracting substance is composed of two oppositely charged atoms and that the specific inductive capacity of the medium may be considered as made up of two parts, one due to the ether itself, and the other to the setting of the molecules along the lines of electric force, we should find that the index of refraction increases with the frequency of the light waves until it is equal to the natural period of vibration of the molecules of the refracting substance. The index of refraction then diminishes, becomes less than unity, and finally approaches unity, as the period of the light waves becomes great in comparison with the free period of the molecules. The relation between the refractive index and the frequency is shown by the following consideration: Let a force of given amplitude act on a mixture of such molecules as are considered in the Helmholtz theory and which have but one natural period of vibration. Then beginning with a frequency of force less than that of the substance, the index of refraction will increase with the increase in the frequency of the force, because the specific inductive capacity increases, due to the fact that more and more of the molecules will swing into line; the effect of the force will be greatest when its period is equal to the natural period of the molecules. After this, as the period of the force becomes greater than the natural period of the molecules, they will topple over so as to oppose the specific inductive capacity due to the ether. If there are a sufficient number of molecules they may overcome the specific inductive capacity due to the ether, so that the specific inductive capacity of the mixture will be negative. Waves of this frequency could not, of course, traverse the medium, but would be totally reflected. Then, as the frequency of the force increases, the effect of the force in making the molecules set will be less and less, and finally the negative part of the specific inductive capacity of the molecules will equal the positive part due to the ether. The index of refraction will then be zero. After this the effect of the

force growing less and less with increase in frequency, the specific inductive capacity approaches that due to the ether alone, *i. e.*, unity.

So far the only experimenters who have obtained any evidences of polarization are Prince Galitzine and Karnojitsky (*C. R.* 122, pp. 717–718, 1896). By a sort of cumulative method they thought they could observe slightly greater absorption with the axes of the tourmaline plates crossed than when the axes were parallel, but these experiments are uncertain and have not been confirmed by other observers. The reason we have not been able to detect any evidences of polarization may be due to the fact that we have not used polarizers of sufficiently fine structure. Long electric waves may be polarized by a very coarse wire grating; DuBois and Rubens succeeded in polarizing the infra-red rays by means of a fine wire grating; while shorter waves would require a very much finer structure.

Thus the absence of polarization and refraction cannot be urged as evidence against the theory that the Röntgen rays are transverse ether waves, but is rather what we should expect if these are very short waves. If the atoms of a vibrating molecule carry an electrical charge, then the electromagnetic theory of light would lead us to expect two kinds of waves, one due to the oscillations of the atom, the other due to the oscillations of the electrical charges carried by these atoms. The wave-length of the latter would be comparable with atomic dimensions. Professor Thomson asks: "Can these be Röntgen rays? and if so we should expect them to be damped with such rapidity as to resemble electrical impulses rather than sustained vibrations."

Professor Stokes thinks (*Nature*, p. 427, 1896) that the many properties which the Becquerel rays have in common with the Röntgen rays almost establishes the fact that the Röntgen rays are due to some kind of transverse vibration. He regards the disturbance as non-periodic, though having certain features in common with a periodic disturbance of very great frequency.

Nearly all observers who have studied the reflection of Röntgen rays were unable to detect any evidence of regular reflection. The only observer who has obtained any result indicating regular reflection is Lord Blythswood (*Proc. R. Soc.*, March 1896). He used two mirrors of polished speculum metal placed side by side to reflect the rays. The negative on development appeared to show the crack separating the mirrors. It may be worth while repeating the experiments using mercury as the reflecting surface. The diffuse reflection may be due

to the fact that surfaces which we regard as highly polished and which reflect waves of ordinary length, may in reality be extremely rough for these very short wave-lengths, or else it may be due, as Stokes suggests, to a kind of phosphorescence produced in the substance of the mirror. The latter view would seem to be supported by some experiments of Thomson in which the reflected rays appear to have different properties (as regards the discharge of electrified bodies) from the incident rays.

M. Gouy (*Jour. de Phys.* 3^{e} série, t. V) in his researches on the refraction and diffraction of the Röntgen rays made use of a form of tube called focal, in which the rays take rise at the surface of a thin plate of platinum placed at the center of curvature of a spherical cathode. The Röntgen rays which start from this flat lamina have a nearly equal intensity in all directions, down to the plane of this lamina. By working thus at very nearly grazing angle he obtained practically a linear source of great intensity, and was thus enabled to place his photographic plate at considerable distance with a reasonably short exposure. He stretched two platinum wires, whose diameter was $0^{mm}.040$, parallel to one another, and at a distance apart of 2^{mm}. Two prisms were placed near the middle of the wire, one opposite each wire, with their refracting angles turned in opposite directions. The two ends of the wire will thus be formed on the photographic plate by the rays which only traversed the air, while the central portion is formed by the rays which have traversed the prisms. The photographs were then mounted on a very accurate dividing engine, and examined for any displacement of the central part of the lines relatively to the two ends. In this way he was enabled to show that, for the transparent substances examined (glass, ebonite, aluminium, etc.), the index of refraction exceeds unity by less than .000001. For the more opaque substances, like Zn and Fe, the accuracy of the experiment is only about one-twentieth of the above. To obtain an idea of the possible wave-length, M. Gouy made use of a well-known diffraction experiment. A slit $0^{mm}.045$ in width was placed at a distance $2^{m}.5$ from a photographic plate on one side, and at an equal distance from the linear source of Röntgen rays on the other side. At a distance of $0^{mm}.055$ from the center of the resulting photograph of the diffraction slit the intensity is far less than one-fourth the maximum intensity. By calculating the wave-length of light which would give as rapid a falling off in intensity as this, he finds that it must be far less than 50.

This experiment, therefore, seems to show that the wave-length of these rays (if they are waves) must be less than $\frac{1}{100}$ that of ordinary green light.

L. Fomm (*Wied. Ann.*, No. 10, 1896), by a somewhat similar experiment with a diffraction slit, places the upper limit of the wave-length at 140. G. Sagnac (*C. R.*, 122, No. 13) uses a wire grating and calculates from a scarcely measurable widening of the image of the slit an upper limit of 400.

Professor Thomson has, by the use of interference fringes, endeavored to detect any motion of the ether near an electric vibrator. As this motion would be oscillatory, and for an undamped vibrator the average velocity would be zero, he has used a heavily damped vibrator, hoping thus to obtain an average velocity which would be finite. The experiment gave a negative result. A similar experiment to detect any motion of the ether around a tube sending out Röntgen radiations was carried out, but failed to show any evidence of ether motion. A similar experiment has been made, independently, by Threlfall and Pollock (*Phil. Mag.*, December 1896) by an application of Michelson's interference experiments. They were unable to detect any shift of the interference bands when the Röntgen radiations were started and stopped. From the limit of accuracy imposed by the conditions of the experiment, they were led to the conclusion that Röntgen radiations are not associated with ether velocities exceeding 177^{m} per second, which is one thousand times less than the velocity of the cathode rays according to the measurements of Professor Thomson.

Among the most noteworthy properties of these rays are their power of rendering all bodies, dielectrics as well as conductors, conductors of electricity (J. J. Thomson and J. A. M'Clelland, *Proc. Phil. Soc. Cambridge*, Vol. IX, Pt. II). A gas which has been thrown into a conducting state by the passage of Röntgen rays, retains for a considerable time its power of discharging electrified bodies. This condition is destroyed if an electric current be passed through the gas. The gas while in this state behaves like a dilute solution of an electrolyte. When a current is sent through a gas which is being exposed to Röntgen radiation, the current destroys and the rays produce the structure which gives conductivity to the gas. When the rate of destruction is equal to the rate of production we have a saturation current, and any further increase in the E. M. F. can cause no further increase in the current. The conducting property which these rays

confer on gases is not destroyed when the gas is passed through metal tubes raised to red heat; it is, however, filtered out, as it were, by passage through water and glass wool. This latter, together with the comparatively slow migration velocity obtained for "ions" of a gas in this state conveying a current, has led Professor Thomson to think that the conducting structure is of a coarse nature, and that we are here perhaps dealing with aggregations of molecules rather than with the more simple ion used to explain electrolytic phenomena (J. J. Thomson and E. Rutherford, *Phil. Mag.*, No. 258). An experiment was made to determine if these rays were generated when the phosphorescence of the glass was produced by other means than the discharge from a negative electrode (Thomson, *Proc. Phil. Soc. Cambridge*, Vol. IX, Part II). For this purpose intense phosphorescence of the glass was produced by a ring discharge in an electrodeless bulb. In a second experiment this tube was filled with oxygen, which itself becomes phosphorescent, but in neither case was any effect observed on the photographic plate. It is, therefore, possible to have phosphorescence without the presence of Röntgen rays. Another experiment was carried out to see whether a negative electrode could produce these rays without the presence of the walls of the tube. For this purpose a piece of photographic plate was enclosed in a small ebonite box and placed inside the tube between the negative electrode and the wall of the tube, but in this case also no effect was produced on the photographic plate.

There is a general agreement among observers that the Röntgen rays discharge bodies, whether electrified positively or negatively; some, however, seem to have obtained evidence of an independent electrification due to the rays, without agreeing as to the sign of this electrification. Gerchun and Borgman find it negative, and Righi positive. Benoist and Hurmuzescu (*Jour. de Phys.*, 5, pp. 358–362, 1896) have repeated the experiments with an improved form of electroscope, and also with an electrometer, but fail to find any evidence of such electrification. Lord Kelvin (*Nature*, December 31, 1896), by an experiment on air, unelectrified to begin with, finds that if such air be exposed to the Röntgen rays it shows decided negative electrification.

Benoist and Hurmuzescu find that the rate of discharge of electrified bodies depends not alone on the intensity of the radiation, but also on the nature of the charged surface. This is similar to the action of ultra-violet light, whose power of discharging bodies also depends

on the nature of the surface, but the order of the metals is not the same in the two cases. For the Röntgen rays the most opaque metals (Pt, Hg, etc.) come at the top of the series, *i. e.*, they are discharged most rapidly, while the metals which are discharged more slowly are the transparent ones like aluminium. From this arrangement of the metals they conclude that the power of the different metals for utilizing the energy of the rays for the dissipation of electricity varies inversely as their transparency. The theory of the pulverization of the metals has been used to explain the phenomena in the case of ultraviolet light, but this is scarcely applicable here, for similar effects were observed when the metals were imbedded in solid dielectric media, such as paraffine. In the investigation of the effect of the surrounding gas, they find that for the same gas at different pressures, or different gases at the same pressure, the rate of discharge is proportional to the square root of the density,

Another interesting property of the Röntgen rays has been pointed out by Aubel (*Jour. de Phys.*, 5, November 1896) who has compared the diathermanous property of bodies and the transparency to these rays. He calls attention to the fact that the presence of the halogens and of sulphur in a molecule increase its diathermancy but renders it more opaque to the rays; while bodies containing the elements carbon, hydrogen, and oxygen allow the rays to pass readily, although they absorb strongly heat radiations. Comparatively thick layers of vapor, however, of such opaque substances as chloride of thallium seemed absolutely transparent.

Mr. C. T. Wilson, by studying the effect of Röntgen rays on cloudy condensation (*Proc. R. Soc.*, March 1896), finds that, while air exposed to the Röntgen rays requires to be expanded just as much as ordinary air in order that condensation may take place, these rays have the effect of greatly increasing the number of drops formed and the time during which the fog remains. In ordinary air the fog settles down in a few seconds, while in the air exposed to the rays it persists for some minutes.

Cajori (*Amer. Jour. Sci.*, 2, 152), who exposed photographic plates, suitably protected from moisture and light, on the top of Pike's Peak, failed to detect any evidence of the Röntgen rays in solar radiation. Similar results have been obtained by Lea (*Amer. Jour. Sci.*, 1, 363–364, 1896) and others.

Winkelmann and Straubel (*Wied. Ann.*, No. 10, 1896) found that

when the Röntgen rays strike upon a plate of fluor-spar and also upon glass containing certain of the rare earths, especially zirconium, they give rise to what they briefly call spar rays. They have studied the spectrum of the spar rays and find that it begins at $\lambda = 3960$, is a maximum at 2800, and ceases at 2330. By placing a piece of spar below the photographic plate they obtain effects many times stronger than if the Röntgen rays alone acted; if a thin sheet of paper is slipped between the sensitive layer and the fluor-spar, its effect is cut off, thus showing that the Röntgen rays that struck upon the surface of the spar must have given rise to new waves, for, had the Röntgen rays been simply reflected, the paper would not have cut them off. Similar effects from phosphorescent sulphide of zinc, have been observed by Henry (*C. R.*, 122, 312–313, 1896). Henry has also found that when a zinc sulphide screen, wrapped in carbon paper, is covered with the object to be examined and exposed to the radiation of a Crookes' tube for some minutes and then removed to a dark room, the image shines for at least one quarter of an hour, so that the smallest details of the image can be made out. The light emitted by glowworms was found to be capable of penetrating blackened paper and affecting a photographic plate.

Experiments by M'Clelland (*Proc. R. Soc.*, No. 360) and others seem to show that the Röntgen radiations from a vacuum bulb are not homogeneous. By measuring the relative transparency of some substance, *e.g.*, glass and tinfoil (by passing the rays through them and observing the rate at which conductors are discharged in the two cases), and then measuring the relative transparency of the same two specimens after the rays have passed through a few additional sheets of tinfoil, it was found different in the two cases. This can only be explained by assuming that the rays are not homogeneous, and some are more readily absorbed by the glass and others by the tinfoil.

In an article by T. C. Gilchrist (*Bull. of the Johns Hopkins Hospital*, 8, No. 71) the effect of the Röntgen rays on the skin and joints is fully discussed. Of the thousands of experiments that have been made with these rays only twenty-three are known to have been followed by injurious effects. In several of these cases the injurious effects have resulted from short exposures.

C. W. Waidner.

Johns Hopkins University,
February 25, 1897.

Über die ultravioletten Funkenspectra der Elemente. Sitzungsberichte d. K. Akad. d W. Wien. Bd. 105, pp. 389–436, 503–574, 707–740, 1896. FRANZ EXNER und E. HASCHEK.

THESE three papers describe a series of measures on more than nineteen thousand ultra-violet lines in the spark spectra of the following eleven elements, viz., Ag, Cu, Mn, W, Mo, Pt, Pd, Ir, Rh, Ru, Os. The spectra were photographed in the ordinary way with a Rowland 5-foot concave grating. Practically all the measures lie between λ 4700 and λ 2100. The blue and violet of the first order spectrum were separated from the ultra-violet of the second order by placing a glass plate so as to cover one-half of the slit. On the part of the photographic plate affected by the uncovered portion of the slit, one has the lines of both orders; while the light which passes through the glass belongs to the first order.

One is naturally curious to learn in what manner the stupendous task of measuring nineteen thousand wave-lengths was approached. Nothing could be simpler. Several methods, we venture to think, might be more accurate. The spectrum to be measured, together with its comparison spectrum, Iron, was projected upon a screen, the image being thirty times larger than the original. On the screen is a half-centimeter scale; this scale is so adjusted that the reading of each of the Rowland standards is its correct wave-length. The unknown wave-lengths are thus interpolated and their values read directly from the scale. By this convenient method, the authors think they have determined their wave-lengths with an error not exceeding 0.1 Ångström unit. They compare their values for 132 Osmium lines with those of Rowland and Tatnall for the same lines, and find the average deviation 0.03 Ångström unit. The results are, therefore, perhaps more accurate than one would imagine when he remembers that the physical width of the line, the grain of the plate, and (between standards) the distortion of the projection-lens, all cut a figure in this method. A series of wave-length determinations possessing this degree of accuracy (0.03 to 0.1 Ångström unit) is of great value. It is the more to be regretted, therefore, that the values are given only to the first decimal place, in contravention to the usual practice of giving results to one place beyond where they are considered thoroughly trustworthy.

Accompanying the text, are beautiful photogravure reproductions

of nearly all the spectra studied. Each strip includes about 700 Ångström units, and is about seven inches long. The separation of the overlapping spectra of different orders is excellently shown on these plates. H. C.

COLOR-PHOTOGRAPHY.

1. *Presidential Address.* W. LECONTE STEVENS. *American Association for the Advancement of Science*, **44**, 45, 1895.
2. *Zur Photographie in naturähnlichen Farben.* P. GLAN. *Wied. Ann.*, **58**, 402.
3. *On a Method of Photography in Natural Colors.* J. JOLY. *Nature*, p. 91, November 28, 1895.
4. *On Color Photography by the Interferential Method.* G. LIPPMANN. *Proc. R. Soc.*, **60**, 10.
5. *Photography in Colors.* *Nature*, p. 318, February 4, 1897.
6. *Photographic Reproduction of Colors.* *Nature*, p. 422, March 11, 1897.

IN the first of these papers we find an account of the work on color-photography up to the year 1895. Of the various methods described, the one perfected by F. E. Ives (*Jour. Franklin Inst.* 125–135) is the most satisfactory. He takes three negatives through three compound color-screens, each adjusted by experiment so as to transmit in the correct proportion all the colors that go to make up one of our primary color sensations. From each of these negatives he prints a positive and dyes the positive red, green, or blue-violet according to the color sensation corresponding to its negative. When such a set of positives are superimposed and viewed by transmitted light we see an exact likeness, in its natural colors, of the object photographed.

In the second paper Glan suggests that, instead of color screens, a direct vision spectroscope might be placed in front of the lens of the camera. Then by a suitable arrangement of diaphragms in the spectroscope we could photograph the object in any colored light desired. Since Ives has shown that we must employ screens of compound, and not of pure colors, I think his method is preferable to Glan's.

Joly's method is based upon the same principle as that of Ives, but he combines the three photographs in one. He takes his negative

through a screen ruled alternately with orange, green, and violet lines. From this he prints a positive, and views the positive through a similar screen ruled in red, green, and violet. When this screen is so adjusted that the red lines are over those parts covered in the negative by the orange lines of the taking screen, the green and violet will lie over the green and violet portions, and if the lines are close enough together, the photograph will appear colored. He rules 300 to 1000 lines to the inch.

Lippmann employs a transparent photographic film, which he backs with a layer of mercury. The light reflected from the mercury interferes with the incident light so as to form standing waves in the film. Under these conditions the reduced silver forms parallel layers whose distances apart at any point are equal to one-half the wave-length of the light incident there. Thus the film is converted into a kind of reflecting grating, and when viewed at the angle of specular reflection, appears colored.

The last paper describes the results of a process of color photography invented by M. Villedieu-Chassagne. He washes an ordinary photographic plate in a colorless solution, takes a negative upon it, and from this he prints a positive upon a similarly prepared plate. Neither negative nor positive is colored, but the positive has the power of absorbing certain dyes in the correct proportions to give the natural colors of the object photographed. The natures of the solution and dyes have not yet been made public.

During an address before the Society of Arts, Sir Henry Trueman Wood exhibited some transparencies taken by a secret process devised by Mr. Bennetto, of Newquay, in Cornwall. They are described as "much clearer than those obtained by the Chassagne process, and look almost like water color sketches." "The colors are imprinted on the plate just as are the light and shade in an ordinary monochrome photograph, and are directly visible to the eye, without any subsidiary apparatus."

N. E. Dorsey.

Johns Hopkins University,
March 11, 1897.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

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NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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PLATE XIX.

S

P  F

VENUS.

1889, MAY, 29^{d} 11^{h} 12^{m} A.M.

12-inch Equatorial. E. E. Barnard.

THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

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PHYSICAL AND MICROMETRICAL OBSERVATIONS OF THE PLANET VENUS, MADE AT THE LICK OBSERVATORY WITH THE 12-INCH AND 36-INCH REFRACTORS.

By E. E. BARNARD.

No OTHER object has caused more controversy and produced more varied testimony in the determination of its rotation period than the planet Venus. This rotation controversy has raged for upwards of two centuries, with fitful periods of quiescence—after some observer more combative than the rest had definitely "settled the question"—only to break out again with renewed virulence when a new champion for rotational honors entered the field.

The periods assigned to the planet vary all the way from twenty-three or twenty-four hours to 225 days. One of the short-period men has gone so far as to produce a period, derived from drawings made a few days apart, with a decimal running into the ten-thousandth of a second, which ought certainly to be convincing enough, as a smaller subdivison of time would be an insensible quantity and ought never to be stickled for in determining the duration of a planetary day.

These discrepancies are due in the main to the difficulty—from various causes—of seeing the markings which really exist on the surface of Venus.

Certainly the prime factor in observations of the surface features of this planet, is a steady atmosphere. Without this one can hope to do little or nothing at all with Venus, no matter how perfect his telescope. When we take into account also that the observations must be made in the daytime to get as high an altitude as possible, we find the difficulty is further augmented, for in the day the atmosphere is never so steady as it often is at night. Take into account, further, that the markings on this planet are exceedingly delicate, with but little contrast, and we have—considering the promise its great brilliancy holds out—perhaps one of the most disappointing objects in the entire heavens.

Venus was frequently observed with the 12-inch refractor at Mt. Hamilton during the years 1888–95, but I never could (with but one exception) satisfactorily see the markings. Vague, indefinite spots were often visible, but it was not possible to see them well enough to identify them for rotational purposes.

The atmospheric conditions at Mt. Hamilton were seldom at all favorable for day observations. The heating of the southern, contrasted with the cooler northern slopes, produced an unsteadiness of the air which was almost always present in the daytime.

There were times, however, when the air was thick with smoke and dust, when the seeing was fairly good. But this condition, though it tended to produce steadiness, was sometimes accompanied with excessively bad seeing, so that it could not always be depended upon as a criterion. A clear blue, transparent atmosphere almost always proved unsteady, and this seemed to hold at night also. Indeed, so marked was this peculiarity that one was wont to say when the sky was a rich dark blue in the day that the night would be bad, so that a dark-blue sky really became synonymous with poor seeing.

The 29th of May, 1889, was remarkable for the thickness of the atmosphere from smoke and dust. One could scarcely see across the cañon so dense was the haze. Examining Venus with the 12-inch on this date I was struck with the remarkably

perfect definition. There was not the slightest tremor of the image. The markings on the surface of the planet were distinctly seen, though they were difficult and very delicate. A careful drawing was made of these details, which were distinct enough to be drawn with perfect satisfaction. This perfection of definition did not last long enough to show any motion in the spots—the ordinary day-seeing soon taking its place.

Venus was looked at at this time with the 36-inch, but the seeing with the great instrument was not perfect enough to show the markings satisfactorily. Indeed, in all subsequent observations of Venus the 12-inch was preferable.

This drawing is herewith presented, and I am satisfied the markings shown exist on Venus and are here closely represented. From their position on the disk it will be seen that they are large broad spots, for they must be greatly foreshortened in their position near the limb.

The circumstances under which this drawing was made are memorable with me, for I never afterwards had such perfect conditions to observe Venus. A close lookout was kept on the planet in hopes of again seeing the spots, but if seen again they were too poorly defined to be recognized. On several dates thereafter when the seeing was fair, the same region seemed to be visible; especially on June 10, 1889, did I have the impression that these markings were present, but the details could not be made out, and probably the three spots were blended into one long vague spot from the lack of definition. On several other dates I seemed to see the same thing, especially on the forenoon of June 12, when a sketch showed about the same appearance.

The planet was watched through many years, but indifferent seeing always baffled one and no satisfaction could be gotten out of it.[1]

In these observations of Venus I have tried various methods to improve the image, such as contracting the aperture of the

[1] On a number of occasions, with both telescopes, I tried to see the dark part of Venus by occulting the bright part, but without success.

object-glass; using a small diaphragm over the eyepiece; using colored glasses, etc. Of these the best results were got by contracting the aperture between the eye and the eye lens of the eyepiece.

I also found it a very great advantage to cover the head and the eye end of the telescope with a large dark cloth to cut out all extraneous light; one has no idea how much this simple method aids in observing a difficult object, either in the day-time or at night, but especially in the day when observing Venus.

In 1895, in conformity with my plan to measure the diameters of all the planets with the 36-inch, I secured a series of measures of the diameter of Venus during the months of May, June, and July, when the planet was approaching inferior conjunction. The customary west wind that springs up nearly every evening during the summer months interfered very much with the observations, often making it impossible to secure measures.

These measures were made with the full aperture of the object-glass except on one date, when it was reduced to twelve inches. A small cap over the eyepiece (next the eye) with a hole in it about $0^{in}.04$ diameter was always used, however. This was very useful in sharpening the image and reducing the glare.

Two magnifying powers were used, 350 and 520. The smaller of these was generally preferred, as the measures were less affected by the oscillation of the image due to wind.

No recognizable markings were seen on the planet during these measures nor at other observations with the 36-inch, though vague suggestions of spots were frequently present.

The measures are of that diameter essentially perpendicular to the orbit of Venus. They are corrected for refraction and in next to the last column are reduced to distance unity ($\triangle$ 1). There does not seem to be any decided systematic difference in the measures due to magnifying power. One or two measures are rather largely discordant, but these can be attributed

to the conditions of observation—shaking of the telescope by the wind or poor definition. No illumination of the wires was necessary and the method of double distance was employed.

In the second column of the following table the standard Pacific times of sunset are given. It will be seen that the measures were made about sunset—some before and some after. It was not possible to measure the planet much after sunset because of the increased disturbance of the image and from the fact that it soon got beyond the reach of the great telescope.

MEASURES OF THE DIAMETER OF VENUS IN 1895.

S. P. T.	Sunset	Mag. power	Seeing	Observed	Δ 1	Resid.
May 6d 7h 6m	6h 59m	350	4	14".43	17".30	+0".10
" 6 7 16	....	520	3	14 .61	17 .51	−0 .11
" 12 7 30	7 4	520	3	14 .99	17 .35	+0 .05
" 13 6 56	7 5	520	3	15 .04	17 .30	+0 .10
" 13 7 3	....	350	3	14 .83	17 .06	+0 .34
June 2 6 54	7 20	520	2–3	17 .16	17 .23	+0 .17
" 2 7 2	....	350	2–3	17 .19	17 .25	+0 .15
" 3 7 20	7 20	350	3	17 .52	17 .45	−0 .05
" 9 6 48	7 24	350	3	18 .44	17 .51	−0 .11
" 9 6 58	....	520	3	18 .27	17 .35	+0 .05
" 10 7 58	7 25	350	2	19 .26	18 .13	−0 .73
" 16 6 17	7 27	350	3	19 .36	17 .32	+0 .08
" 16 6 20	....	520	2	19 .35	17 .31	+0 .09
" 17 7 5	7 27	350	2	19 99	17 .73	−0 .33
" 17 7 10	....	520	2	20 .10	17 .83	−0 .43
" 24 7 25	7 29	350	4	20 .59	17 .10	+0 .30
" 30 6 25	7 29	350	3	22 .23	17 .39	+0 .01
" 30 6 30	....	520	3	22 .33	17 .47	−0 .07
July 1 7 23	7 29	350	4	22 .33	17 .28	+0 .12
" 1 7 29	....	520	3	22 .65	17 .53	−0 .13
" 7 7 55	7 28	350	3–4	24 .38	17 .67	−0 .27
" 8 7 27	7 28	350	2–3	24 .03	17 .23	+0 .17
" 14 7 10	7 26	350	3–4	25 .57	17 .09	+0 .31
" 14 7 18	....	520	3–4	25 .63	17 .13	+0 .27
Mean..........					17".397	

The mean of these measures reduced to distance unity gives 17".397 for the diameter of Venus, which corresponds to an actual diameter of 7826 miles.

NOTES ON THE MEASURES.

1895, May	6.	Planet clearly defined. No spots seen. Measures good.
"	6.	Image unsteady. Seeing getting bad.
"	12.	Very heavy wind shaking telescope. Image oscillating badly.
"	13.	Measures very good.
1895, May	13.	Not a tremor of the image from wind or vibration of the telescope.
June	9.	Image jumping and fluttery.
"	10.	Wind shaking telescope.
"	16.	High northwest wind, but not striking telescope.
"	24.	Wind shaking telescope too much to use higher power.
"	30.	Wind shaking telescope.
July	1.	No wind.
"	14.	Slight wind shaking telescope. Aperture reduced to twelve inches No definite markings.

In *A. N.*, 3204, Bd. 134, Dr. L. Ambronn gives his measures of the diameter of Venus, made during 1892, with the great heliometer at Göttingen. I am indebted to his paper for the following list of previous measures of the diameter of Venus, including his own measures in 1892.

These measures will be interesting in comparison with those made with the 36-inch.

(1) E. Hartwig, Breslau heliometer - - - - -	17".67
(2) E. Hartwig's reduction of the Oxford measures - -	17 .582
(3) E. Hartwig, from double-image observations by Kaiser	17 .409
(4) E. Hartwig, nine measures in Bahia-Blanca - -	17 .406
(5) B. Peter, two measures in Bahia-Blanca - -	17 .216
(6) F. Küstner, two measures in Punta Arenas - -	17 .312
(7) A. Auwers, measures during transit - - -	16 .801
(8) L. Ambronn, Göttingen heliometer - - - - -	17 .711
Mean - - - - - - - -	17".389

It will be seen that these are in very close agreement with my measures with the 36-inch in 1895.

YERKES OBSERVATORY,
April 1897.

NOTES ON THE DETERMINATION OF THE FOCUS OF AN OBJECTIVE.

By H. C. LORD.

IN photographing stellar spectra with the compound star spectroscope, it is of the utmost importance that the slit be placed accurately in the focal plane of the great objective, for the particular part of the spectrum to be examined. This is especially true when the so-called achromatic objective is corrected for the visual portion of the spectrum. As I have been unable to find any published directions as to the proper method of accomplishing this result, which were at the same time specific and accurate, or any experiments which would show the precision to be expected, I have thought that my experience with different methods tried and the results obtained might not be without interest to the readers of the ASTROPHYSICAL JOURNAL.

The instruments used were the twelve and one-half inch equatorial and large star spectroscope of the Emerson McMillin Observatory, which are fully described in the ASTROPHYSICAL JOURNAL, 4, 1. The battery of two prisms was used in every case. A less dispersion might have been better, but I was anxious to use the instrument under the same conditions as those in which it was to be used for regular work.

The first method tried was that due to Professor Young and described in the *American Journal of Science*, No. CXIV, namely, of placing the limb of the Sun over one-half the slit and focusing until the line of division of the bright and faint spectra appeared sharp. The seeing was never good enough for this method to give even an approximate place. The same method was tried, using the Moon in place of the Sun. The results were much more accurate, but on account of the faintness of the lunar spectrum it was difficult to accurately focus the observing telescope. The following plan was then tried: The reading of the scale on the draw-tube of the observing telescope,

when $H\beta$ was in focus, the line used in all my experiments, was determined from a number of pointings on the Sun. These were made at widely differing temperatures and the setting found to be constant within $0^{mm}.1$. At night, with a small electric lamp placed in front of the slit so as to show a continuous spectrum and the prisms so placed that $H\beta$ was under the cross wires and the observing telescope set at the proper scale reading, the eyepiece was focused on the cross wire, which appeared dark on a colored field. The telescope was then turned upon a star and the whole collimator racked in and out until the spectrum appeared linear where it was crossed by the cross wire. Five pointings were made, the eyepiece being focused between each pointing. Temperatures were read from two thermometers graduated to $\frac{1}{2}°$ F., placed one near the objective and one on the spectroscope, the mean of the two being taken as the temperature. In this manner fairly accordant results were obtained at first. The results are given in the table below together with the focus computed by a formula whose derivation will be described later. After October 10 my eye had a long rest until November 6, when a focus for 50° F. was found which was higher than that previously found for 62° F. Similar results were obtained on November 9. I attributed this to the inability of the observer to prevent his eye accommodating itself to slight changes in focus.

This method was then abandoned and the following photographic method was adopted. The scale reading of the camera for the $H\beta$ focus was determined as before from the Sun, both photographically and by means of a small eyepiece slide which takes the place of the plate holder. Both methods gave the same result. The slit of the spectroscope was then set parallel to an hour circle, in order to have the resulting photograph as narrow as possible, the telescope turned on Polaris and a series of from five to seven exposures given with the collimator set at a different point for each. These points differ by $0^{mm}.5$ in all except those made on November 30, which differed by a single millimeter. Temperatures were read from two ther-

mometers placed as before, readings being taken at the end of each exposure. The average of all was taken as the temperature. At the end of the exposure the artificial $H\beta$ was photographed on the plate. The distance from the $H\beta$ line to the point on the spectrum where it was narrowest was then measured. This could not be told closer than the nearest millimeter, though the results were read to the nearest fifth millimeter. In selecting this point the eye is guided by three factors. The spectrum should be the narrowest, the edges the sharpest, and bearing in mind the color sensitiveness of the plate used, the density should be the greatest. Let this measured distance be d, s the scale reading at which the negative was made, s_0 the scale reading for the given temperature when $H\beta$ is in focus, m s a constant depending upon the slope of the color curve at that point; then evidently $s = s_0 + dm$. d and s are given by observation. Each plate gives one equation and from these equations the values of s_0 and m were calculated by the method of least squares. Each series of plates were measured on three different days.

This method has proved entirely satisfactory, and the results are given in the following table. The 4th, 5th, and 6th columns give the focus determined from any set of plates on each of the three days that it was measured. The 7th gives the means of I, II, and III. From these means the temperature equation $s_0 = 20^{mm}.6 + 0^{mm}.037\ (T^{\circ} - 0^{\circ})$ was computed by the method of least squares. The 7th column gives the value of s_0 computed from the formula for the given temperature. The columns 10, 11, and 12 give the values of m. Column 14 gives the temperature at which the visual observations were made, 15 the observed focus, 16 the focus computed from the preceding formula. This table brings out several facts: (1) That the eye tends to give a constant error in the position of the focus amounting to nearly 1^{mm}, a quantity too large to be neglected. (2) It shows that the photographic method gives much more accordant results than the visual method. (3) The constancy of the value of m, taken in connection with the close agreement of the results for the focus, will tend to show that the accuracy reached is real

PHOTOGRAPHIC.

Date	No. plates	Temp. F.	Focus for $H\beta$ I	Focus for $H\beta$ II	Focus for $H\beta$ III	Focus for $H\beta$ Mean	Comp. focus	C—O	M I	M II	M III
1897—January 25...	6	$-5°.5$	$20^{mm}.3$	$20^{mm}.5$	$20^{mm}.2$	$20^{mm}.3$	$20^{mm}.4$	$+0^{mm}.1$	−0.31	−0.35	−0.32
1897—*February 26.	6	+16 .6	20 .9	20 .8	20 .9	20 .9	21 .2	+0 .3	−0.31	−0.31	−0.37
1897—*February 27.	5	+17 .7	21 .4	21 .4	21 .5	21 .4	21 .3	−0 .1	−0.30	−0.32	−0.36
1896—November 30.	5	+17 .8	21 .4	21 .1	21 .3	21 .3	21 .3	±0 .0	−0.37	−0.33	−0.33
1897—February 27..	5	+18 .0	21 .6	21 .8	21 .5	21 .6	21 .3	−0 .3	−0.31	−0.37	−0.32
1896—December 1..	5	+18 .5	21 .4	21 .4	21 .5	21 .4	21 .3	−0 .1	−0.38	−0.25	−0.29
1897—February 27..	5	+19 .0	21 .4	21 .4	21 .1	21 .3	21 .3	±0 .0	−0.35	−0.32	−0.35
1896—December 3..	5	+24 .5	21 .7	21 .4	21 .7	21 .6	21 .5	−0 .1	−0.27	−0.40	−0.35
1897—*February 24	6	+30 .5	21 .4	21 .4	21 .7	21 .5	21 .7	+0 .2	−0.34	−0.22	−0.34
1897—March 7.....	5	+34 .5	21 .9	21 .8	21 .7	21 .8	21 .9	+0 .1	−0.31	−0.32	−0.30
1896—December 5..	6	+42 .0	22 .4	22 .0	22 .0	22 .1	22 .2	+0 .1	−0.44	−0.37	−0.39
1896—December 9..	7	+44 .0	22 .4	22 .1	22 .4	22 .3	22 .2	−0 .1	−0.27	−0.34	−0.34

*On these dates camera set $0^{mm}.1$ wrong.

NOTE.—On February 27 three sets of negatives were made.

and not simply an accident of observing. It should be stated that though during this set of observations the spectroscope was frequently removed from the telescope, the system of stops provided on the instrument kept the distance, spectroscope to objective, constant.

VISUAL.

Date	Temp. F.	Obs. focus	Comp. focus	C—O
1896—September 1	62°.0	21mm.4	22mm.9	+1mm.5
1896—September 4	63 .2	22 .2	22 .9	+0 .7
1896—September 9	72 .7	22 .5	23 .3	+0 .8
1896—September 19	51 .8	21 .1	22 .5	+1 .4
1896—September 22	46 .0	20 .5	22 .3	+1 .8
1896—September 25	65 .2	22 .0	23 .0	+1 .0
1896—September 26	70 .3	22 .2	23 .2	+1 .0
1896—October 3	51 .8	21 .7	22 .5	+0 .8
1896—October 4	55 .0	21 .4	22 .6	+1 .2
1896—October 8	47 .4	21 .3	22 .4	+1 .1
1896—October 9	49 .0	21 .2	22 .4	+1 .2
1896—October 10	52 .2	21 .1	22 .5	+1 .4
1896—November 6	49 .8	22 .0	22 .4	+0 .4
1896—November 9	33 .6	21 .2	21 .8	+0 .6
1896—November 9	33 .9	21 .4	21 .9	+0 .5

THE YERKES OBSERVATORY OF THE UNIVERSITY OF CHICAGO.

III. THE INSTRUMENT AND OPTICAL SHOPS, AND THE POWER HOUSE.[1]

By George E. Hale.

THE INSTRUMENT SHOP.

Many of the problems which confront the modern astronomer and astrophysicist require for their solution the invention of new methods of research and the construction of instruments of special design. This is particularly true in astrophysical work, and an observatory in which such investigations are to be carried on must be prepared to supply the needed apparatus. Fortunately for the progress of science in the United States, the instruments manufactured by the best firms in this country are not surpassed, if they are equaled, by those made abroad. As this is true of both the optical and mechanical parts, it is evident that no institution having the necessary funds at its disposal need have any difficulty in procuring the apparatus it requires.

The writer had found at the Kenwood Observatory, however, that while the principal instruments could be most advantageously obtained from Brashear and Warner & Swasey, it was necessary to have a workshop in which a skilled mechanician was almost constantly employed in constructing the numerous pieces of apparatus required in the solar and spectroscopic work. Those who have devised new instruments of research know only too well that it is frequently necessary to completely rebuild a piece of apparatus, or at least to make extensive alterations in it, before the expected results can be obtained. If an instrument is built under the eye of its designer, the ideas which may suggest themselves during its construction can be embodied in it at a minimum of cost. In fact, the very opportunity to see

[1] For previous articles in this series see the March and April numbers of this Journal.

PLATE XX.

INSTRUMENT SHOP OF THE YERKES OBSERVATORY.

each part made is not to be undervalued, for one not only obtains in this way a very intimate acquaintance with every detail, but is also much more likely to find important improvements suggesting themselves, which can be at once realized. For much experimental work it is also quite unnecessary to go to the expense of purchasing a finished piece of apparatus, when something answering equally well can be put together under one's own direction in a very short time. Another great advantage of having an instrument shop is the fact that repairs can be made at the moment they are needed, so that an important investigation need not suffer unduly from the results of an accident.

It seemed evident that if an instrument shop had proved to be indispensable at so small an institution as the Kenwood Observatory, it would be necessary to provide the Yerkes Observatory with the very best facilities for mechanical work. The machine tools which had been used for some years at Chicago were an engine-lathe, a shaper, and a small speed lathe. Subsequently there had been added an 8-inch Rivett "Precision" lathe and a Brown & Sharpe universal milling machine. These, with a large number of hand tools for wood and metal working, were available for the purposes of the Yerkes Observatory. It was decided to add to them at once a planer and a drill press, together with a circular saw and speed lathes for pattern work.

It had at first been planned to have the workshop in the power-house, but after it had been found that for various reasons this could not be done, rooms on the lower floor of the Observatory building were selected for the purpose. Professor Wadsworth, who had been placed in charge of the work of designing and constructing instruments, laid out the plan of the shop. A room 18 × 54 feet, occupying the southeast quarter of the ground floor,[1] was devoted to the metal-working tools, and smaller rooms, in the hall adjoining this on the east, were fitted up as pattern shop and forge room. To lessen the effects of vibration of the machinery, the cement floors of the shop are

[1] See Plate XI in the April number of this JOURNAL.

separated from the walls by strips of soft wood. For the same reason the main shaft, which runs the entire length of the large room, and extends through the partition into the pattern shop, is not hung from the ceiling, but supported from the floor. The countershafts, also, are mounted on floor supports, no shafting of any kind being attached to the ceiling. The results of this plan are very satisfactory, and up to the present time no traces of vibration have been detected, although sensitive instruments have been used in various parts of the building.

As the photographs show (Plates XX and XXI), the heavier machinery, consisting of a 16-inch Blaisdell engine lathe, Prentice drill press, 20 × 20 Wheeler planer, Brown & Sharpe universal milling machine, and shaper, have been grouped in the west half of the large shop. In this part of the shop there are also an emery grinder, speed lathe, bench for filing and chipping, and soldering bench. The motor which furnishes the power is a transformed 70-light Weston dynamo formerly used by the writer at the Kenwood Observatory to generate the current employed in his studies of the spectrum of the electric arc. But few alterations were required to adapt it to its present purpose, for which it serves very well.

The more delicate instrument work is done at the east end of the shop in a room separated from the space just described by a glass partition.[1] A filing bench runs the entire length of the south wall of this room, and is carried around on to the east wall. Upon this bench is mounted an 8-inch Rivett "Precision" lathe fitted with grinding attachment, Horton chuck, step chuck, and a set of split chucks. The change gears permit threads to be cut on both the English and metric systems. The shop is provided with a good collection of small tools.

The machine tools in the pattern shop consist of a circular saw with iron tilting table, and a large face-plate lathe of nine feet swing designed for pattern work and built by our own mechanicians. There is also a cabinetmaker's bench and a good assortment of wood tools. The adjoining forge room

[1] Not completed when the photograph reproduced in Plate XX was taken.

PLATE XXI.

INSTRUMENT SHOP OF THE YERKES OBSERVATORY.

contains a forge with hand blower, and a blacksmith's anvil with the necessary small tools.

The shops have been fitted up during the past winter by Professor Wadsworth and the two mechanicians. Although this has necessarily taken up much time, opportunity has nevertheless been found for other work. Among the machines and instruments constructed may be mentioned the 9-foot pattern lathe, planer chuck, large spectroscope,[1] rotating shutter for solar photography, set of universal clamps and supports for the laboratories, and an alt-azimuth mounting for a 24-inch reflector.[2] The 12-inch telescope of the Kenwood Observatory has been remodeled to adapt it to the higher latitude and different conditions of work of the Yerkes Observatory. The large spectroheliograph has also been partly rebuilt, and a grinding machine for the optical shop is now in process of construction. In addition to this much repair work has been done.

Two skilled mechanicians are employed in the shop. A recent gift from a friend of science in Chicago for the express purpose of constructing a machine for ruling gratings, designed by Professor Wadsworth, will now render possible the employment of a third mechanician, whose entire time will be devoted to this work. An interferometer will be required in perfecting the adjustments of the ruling machine. This will be constructed first in order that it may also be employed in Professor Wadsworth's determinations of the absolute wave-lengths of lines in the infra-red spectra of the elements. In addition to the ruling machine the most important instrument now being built in the shop is a 24-inch heliostat, castings for which are shown on the engine lathe and planer in Plate XXI.

THE OPTICAL SHOP.

According to a well-known saying, a reflecting telescope can be successfully used only by its maker. While this is of course not strictly true, the history of the larger reflectors has been

[1] Shown in Plate XVII in the April number of this JOURNAL.

[2] Shown in Plate XV in the April number of this JOURNAL.

such as to emphasize the meaning which it is intended to convey. No one can appreciate so well as the maker the peculiar sensitiveness of specula, and no one is so well prepared to overcome the difficulties encountered in their use. As the light-grasping power of specula depends upon the condition of the reflecting surface, it is of great importance that the silver film be kept highly polished, and that it be replaced by fresh silver when necessary. Recognizing from the outset the superiority of reflectors for stellar spectroscopic work,[1] the writer has always planned that the Yerkes Observatory should be provided with a large reflecting telescope as soon as circumstances would permit. It was thought best to secure the services of an optician to grind and polish the mirror at the Observatory, and subsequently to keep it in good condition. There was much other work for an optician to do, and it will be gathered from what follows that this plan of supplying our own needs, so far as it can be done to advantage, has not proved unprofitable.

Mr. G. Willis Ritchey, at one time assistant in the Cincinnati Observatory and later in charge of the woodworking department of the Chicago Manual Training School, was engaged in the spring of 1896 as optician. For many years Mr. Ritchey had carried on optical work as an amateur, and at the time of his appointment he had completed an excellent speculum of twenty-four inches aperture and only eight feet focus.[2] A 24-inch speculum of the same focal length as the Yerkes telescope (61 feet) now used in the writer's bolometric work, was made by Mr. Ritchey in a few weeks. This mirror well illustrates one of the most important advantages of the optical shop. For obvious reasons a professional optician frequently objects to sending out work which he regards as in any sense incomplete. As a bolometer one-sixth of an inch wide was to be used at the focus of this mirror, it is evident that it was wholly unnecessary to go to the expense of parabolizing. The desired spherical

[1] See a paper "On the Comparative Value of Refracting and Reflecting Telescopes for Astrophysical Investigations," this JOURNAL, 5, 119, 1897.

[2] Now temporarily used on an alt-azimuth mounting in the heliostat room.

figure was obtained in a very short time, and the total cost was only a small fraction of the regular optician's price for a finished parabolic mirror of the same dimensions. Later, if it is desired to use the mirror for other purposes, the parabolic figure can easily be obtained.

Almost the entire work of fitting up the unfinished north room (20 × 70 feet) which was chosen for the optical shop, has been done by Mr. Ritchey. Two rooms were partitioned off for the grinding machines. The larger of the two (20 × 21 feet) is to contain a machine designed by Mr. Ritchey for grinding and figuring a 60-inch glass disk. This large grinding machine is designed so as to allow the mirror, which lies horizontally during the grinding and polishing, to be quickly inclined to a nearly vertical position when it is to be tested. Two cranks, with adjustable throw or stroke, are used to give the desired motion to the grinding and polishing tools, the mirror, as usual, revolving slowly beneath these tools. The arms which communicate the motion of the cranks to the tools, can be lengthened or shortened while the machine is in motion, thus allowing changes in the position of the tools upon the glass to be made with ease and smoothness. One of these arms also carries the mechanism which rigorously controls the slow rotation of the grinding and polishing tools; and the same arm carries a lever for counterpoising a part of the weight of the tools during the process of grinding and polishing. Since the large disk of glass for the 60-inch mirror weighs nearly a ton, and the grinding tools several hundred pounds each, a strong lever, properly mounted and counterpoised, is necessary for lifting the glass and tools on and off the machine. The metal parts of this machine are being made in the instrument shop, and the heavy wooden frame is to be built by Mr. Ritchey.

The smaller room, 12 × 20 feet, contains the grinding machine used in making the two 24-inch mirrors already referred to. Mr. Ritchey will soon make on this machine a 24-inch flat mirror for the new heliostat. A line shaft running near the floor under a long bench by the windows is driven by an electric

motor. The grinding machines are connected with this shaft by means of a set of friction disks, so arranged that the speed of the machines can be varied through a wide range by the simple motion of a lever. Thus a variation of from 6 to 60 strokes of the tool per minute can be obtained while running.

The optical shop was prepared for use by covering the brick walls with two thicknesses of heavy building paper, separated from the wall and from each other by wood strips, thus leaving two air spaces. The lapped joints of the paper were firmly fastened with outside wood strips, and the whole was varnished. As a further means of maintaining the temperature constant, and of excluding dust, the windows of the grinding rooms are provided with a second inner sash, built in practically air tight. The line shaft is carefully boxed in, and the cement floor is painted. Both grinding rooms have doors in their west walls, which are opened when mirrors are to be tested by Foucault's method. By opening doors in the adjoining halls, a space 175 feet long becomes available for testing purposes. The room next the smaller grinding room contains the electric motor, and is fitted up with table and sink for silvering, the preparation of pitch tools and similar work.

A disk of glass 60 inches in diameter and 8 inches thick is expected to arrive shortly from the plate-glass works of St. Gobain, France. As soon as the large grinding machine is finished, this will be made into the large speculum for stellar spectroscopic work referred to above.

THE POWER HOUSE.

Power is needed in the Yerkes Observatory for many purposes. The motions of the 40-inch telescope are produced by five different electric motors, and the rising-floor and 90-foot dome are operated by two motors of greater horse-power. As has been stated, the instrument and optical shops receive their power from electric motors and the entire building is lighted by incandescent lamps. In order to furnish suitable means of generating power at a distance from the Observatory, Mr. Yerkes

PLATE XXII.

POWER HOUSE OF THE YERKES OBSERVATORY.

has provided a separate brick building (Plate XXII) for the power and heating plant. The equipment of this building, all of which was generously presented to the Observatory by Mr. Yerkes, consists of two 8×10 Ideal engines, each carrying a direct-connected Siemens & Halske dynamo, with a capacity of 200 amperes at 125 volts. The switchboard is so arranged that either dynamo can be used to furnish both power and light while the other is idle. Steam is supplied by two 14×48 tubular boilers, equipped with Gulickson smokeless furnaces and grates. A duplex feed pump, connected with a feed-water heater and oil separator, furnishes the boilers with water. A well under the power-house, 165 feet deep, fed by springs, insures a constant water supply. From it a deep-well pump forces the water to three large receiving tanks in the Observatory building. The further equipment of the power-house includes automatic appliances for the control of steam and water, so arranged that the engineer can tell at a glance the condition of the entire system.

The chimney of the power-house is about 750 feet from the center of the large dome, in a direction (north of east) from which the wind very rarely blows. Up to the present time the small amount of smoke emitted by it has not given the slightest inconvenience. In case it should do so the efficient smoke consumers attached to the boilers could be brought into service. It has been found that they will almost instantly reduce a heavy cloud of black smoke to a hardly visible vapor.

The steam-pipes for heating, electric cables for power and light, and the water pipes are led underground from the power-house to the Observatory. Mr. E. N. Myers is the engineer in charge of the heating and power plant.

YERKES OBSERVATORY,
April 1897.

(*To be continued.*)

AUTOMATIC PHOTOGRAPHY OF THE CORONA.

By David P. Todd.

The great variety of problems arising in the photography of the corona and its spectrum, and yet unsolved, led to the equipment of the Amherst Eclipse Expedition to Japan last year with a type of apparatus essentially novel. The uncertainty of clear August skies in the Hokkaido also contributed to this decision; for should totality be cloudy, as unfortunately proved to be the case, the expedition might still bring back results of much significance in further eclipse work, provided the practicability of operating a large number of photographic instruments as an automaton could be demonstrated.

My attention was first called to this subject in 1878, on the return of the government expeditions to Washington. Excellent photographs had been obtained; but the number of instruments available for a manual routine and the number of photographs obtainable by hand-exposure struck me as exceedingly meager for an occasion when, like a total eclipse of the Sun, the money value of a single second is often hundreds of dollars. And this would still be true even if the human mechanism remained unperturbed under the strain and tension of totality; but sad experience shows its frailty, as attested by numerous and unfortunate instances of slips in the execution of a perfectly arranged programme, no matter how constantly rehearsed.

Then, too, the few exposures with any given instrument ordinarily precludes the chance of experimenting in the development of the negative. If a single series of exposures is obtained, representing a complete range in time, and one of these is developed too far, it is extremely desirable to have at hand an exact duplicate as to instrument and exposure; for the error of judgment may then be corrected. Also the detailed study of characteristic coronal forms has so far been greatly

hampered by the lack of sufficiently large numbers of original negatives for distribution among prominent students of solar physics; even the best transfer from a negative of the corona rarely shows everything that the original does. Our only present available method is to secure originals in sufficient abundance for extended distribution. This demands a great reduction of the time ordinarily lost in changing plates by hand; and the work of our expedition has proved, notwithstanding the clouds, that all the conditions can be amply met by the ease, precision and certainty of well-devised and carefully constructed mechanical movements.

Besides all this there is a wide range of questions not yet solved, for the testimony of past eclipses is by no means uniform: whether small instruments may not be equally effective with large ones; whether reflectors are superior to refractors; the proper sort of instrument to depict the faint outlying streamers, and the more important question of exposure suitable for them; whether the wet process may not be superior to the dry; whether orthochromatic screens should be used, and of what shade; how may the very bright inner and the excessively faint outer coronas be photographed on a single plate; and so on. Naturally we get some light on these questions from exposures upon the Moon and other objects, but the conditions of an eclipse are so divergent from the ordinary that, in the present state of coronal photography, they necessitate relative experiment with different instruments and processes side by side, and upon the corona itself.

The operation of twenty or thirty instruments by hand is out of the question, even if human nerves were infallible. To accomplish the desired end by mechanical devices three systems are feasible:

(*a*) All the mechanical movements may be effected by levers and cords and pulleys directly connected. This system was first worked out in crude form, with the contrivances at our disposal, at the eclipse station in Shirakawa, Japan, in August 1887. P. A. Engineer John Pemberton, U. S. Navy, rendered

very great assistance in the practical details. Our instruments were not of a type to lend themselves very handily to these constructions, but the lever system proved very practical and positive although cumbersome and limited in its application.

(*b*) Prior to the expedition to West Africa under my charge, for the eclipse of the 22d December 1889, a complete pneumatic system of automatic instruments had been worked out and constructed with the assistance of Professor Bigelow. Then it was demonstrated for the first time practicable for a few observers to take a very large quantity of specialized apparatus into the field, mount and adjust it, expose the plates, develop and return them to fellow investigators for whom the time and fatigue of long journeys could be spared. But most unfortunately an accident of the day in the shape of an untimely cloud precluded totality-pictures, although the multitude of novel photographic devices proved itself fully competent to the task marked out for it.

(*c*) It was not any uncertainty in the working of the pneumatic system which led to its abandonment last summer for the trial of the third or electric system of control, but rather the greater convenience in leading wires than pipes, not to say also the greater simplicity of construction and operation of the electric commutator, as described farther on. Extended experience with all three systems has convinced me that this last is decidedly the best; and it has shown itself perfectly competent to operate any available number of eclipse instruments whose record can be obtained photographically. Not only does it accomplish this accurately and positively, but it likewise makes the time-record of every automatic movement in identifiable form.

Early in the autumn of 1895 Mr. D. Willis James, a trustee of Amherst College, and his son, Arthur Curtiss James, a graduate, generously tendered the use of their splendid schooner yacht, "The Coronet," to convey an expedition to Japan for observing the total eclipse of the Sun. In August last year Mr. Pemberton was again one of my faithful coadjutors, by the

courteous permission of the Secretary of the Navy; Professor Pickering, of the Harvard Observatory, kindly gave Mr. Gerrish, well-known for his ready skill in astronomical devices and constructions, leave to accompany us; Mr. E. A. Thompson, a practical and inventive expert, was engaged as chief constructing mechanician, and our instruments were in large part built by him and his sons Herbert and Frank; and in Japan a highly skillful artist, Mr. K. Ogawa, and his assistants, were engaged for the purpose of carrying out our abundant photographic plans. Both the wet process and the dry were employed.

As in the African expedition seven years previously, the instruments were provided by the kind coöperation of many individuals and institutions, to whom full credit is given in the report of our expedition. In all twenty photographic instruments were worked into the automatic system, and complete preparations were made which, but for an unhappy repetition of our experience in West Africa, would have given us more than four hundred exposures with several types of reflecting and refracting telescopes, photographic doublets, a pair of spectroscopes, photometers, and a pair of polariscopes.

The precision of working of all this complicated system of apparatus has thoroughly convinced me of its absolute practicability. I am satisfied, too, that the mechanical principles involved have been thought out and experimented upon with such care and completeness that the detailed constructions may now be published for the benefit of others who, like myself, are convinced that the infrequent availability of eclipses renders it incumbent upon us to extend the duration of totality from three minutes to thirty on every possible opportunity.

Pending the fuller publication in the report of our expedition, in which all the constructions and devices are given with working drawings, I have pleasure in presenting to the readers of the ASTROPHYSICAL JOURNAL, by the courtesy of Professor Hale, the following description of one type of automatic movement which we found most practicable, together with a descrip-

tion of the electric commutator, by which the circuits of all the instruments were unerringly controlled.

Numerous devices for experimental shutters have been tried, but the type found best adapted to quick automatic control is a hollow rotary cylinder with a clear space cut through it, as shown in Plate XXIII (upper left-hand side). Alternate quarter turns open and close it, and the rotation is under the precise, speedy, and effective control of an electric escapement permitting only a single quarter turn at each closing of the circuit. Below it and to the right is shown the plate movement. It is a four-sided barrel, whose revolution is effected by a long and powerful spiral spring wound round its journal. The "fly" of a striker movement in an ordinary clock is connected with a pulley on the axis of the plate-barrel, and serves to make its working positive and yet not too rapid. This device is perhaps the best of our constructions; it keeps abundant power in proper check, and the detent-pins on the face of the barrel stop without any jar on meeting the escapement-pallets. Freedom from jar is a fundamental essential in all the automatic movements when several instruments are mounted on the same polar axis; for the tremor of the shutter and plate movement of one might ruin the definition of another where an exposure is in progress. The plates are slipped into holders strung together in a jointed but inextensible chain, which passes over the four-sided plate drum. A long chain of plates of any desired size is easily within the capacity of this construction. The heaviest loads thrown upon instruments of this type were a chain of 24 plates 8×10 inches, and 150 plates 2×2½ inches. Both showed themselves capable of perfect working. The particular movement shown in the illustration handled 36 plates 4×5 inches. The large diagonal slide was constructed for automatic working by an armature as figured on its right side, gravity furnishing the power; and two orthochromatic screens, one orange and the other neutral tint, were mounted in the two apertures, and permitted to descend between barrel and shutter at the instant required. At first the plate drum and shutter were both moved independently by cir-

PLATE XXIII.

TYPE OF AUTOMATIC SHUTTER WITH PLATE MOVEMENT.

cuits from the commutator; but in our final instruments a contact spring was attached to each shutter, and an independent circuit through it controlled the shifting of the plates.

The basis of the commutator is an old chronograph with a ten-inch cylinder. Its movement was reconstructed so as to eliminate all backlash. At the right-hand end of the barrel is a coarse feed screw, and held rigidly in gear with it by a spring is a half-nut attached to the bent arm leading upward to the sliding-board to which the contact comb is secured. The number of contact springs, or teeth of this comb, is forty-eight. The barrel revolves, like that of an ordinary chronograph, once in sixty seconds. As totality was not to exceed three minutes, the contact springs, or teeth of the comb, were placed at a distance apart equal to three threads of the feed-screw. The barrel, originally of wood, was replaced by hard-rubber ends and a periphery of thin sheets of planished copper. Small brass contact pins were secured to the cylinder wherever a contact was required by boring into the copper sheets and tapping. The pins were then screwed in firmly against a small shoulder on each, affording rigidity and perfect contact with the copper. To facilitate placing them the barrel was mounted in a lathe and a delicate spiral traced over its entire length, using the same feed employed in cutting the feed-screw for the contact comb. Exact correspondence was thus secured. At ten-second intervals fine longitudinal lines were drawn across the barrel, and the number of each tenth-second, continuously from 0 to 8640, was engraved at the point of its intersection with the spiral. By this simple device it was possible to locate the position of each pin in a few seconds, and to verify it from the complete index of contacts. This was carefully calculated in advance, and embodied the full scheme of automatic movements for each instrument. As the number of independent circuits was forty-eight, all capable of operation by the commutator for 180 seconds, and any pin could be placed with accuracy to $\frac{1}{20}$ of a second, the ultimate capacity of the instrument is expressed by the product of these, or rather more than 170,000. Above the commutator is shown the

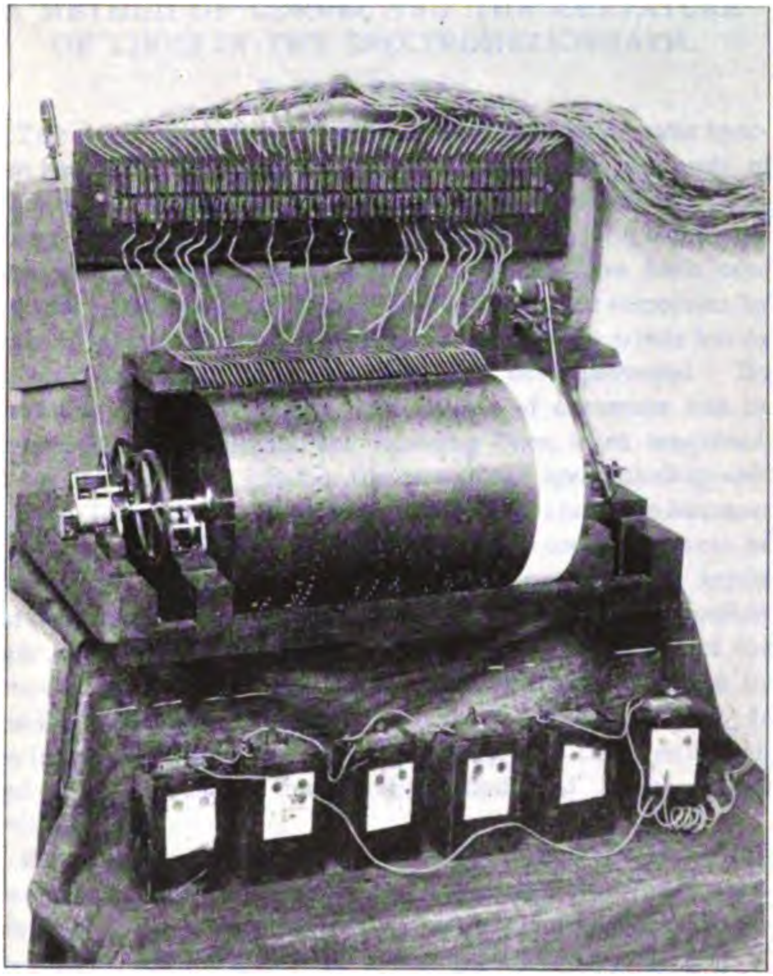
switchboard, by means of which any desired combination of instruments might be effected. It was especially useful in the preliminary experiments. The current was furnished by twelve Edison-Lalande cells of type *S* (not shown) reinforced by six dry batteries of an excellent form manufactured in Tōkyō. A fillet wound round the end of the commutator barrel recorded its running by means of a pen and clock circuit in the usual manner. Thereby the commutator performed the double duty, not only of making the exposures themselves, but of recording with precision the beginning and end of each.

Among other instruments designed and constructed by the expedition, to operate automatically by the commutator, was one which, it is hoped, may assist in the difficult task of photographing both the bright inner and the faint outer coronas on a single plate. Some, then, at least of the complex filaments may be studied throughout their entire length. At the beginning of exposure, three concentric rings and one central disk intercept all rays from the corona, except those of the outlying streamers. In proper succession the rings, followed by the disk, rise automatically, and quickly remove from the photographic field, thereby allowing a differential exposure of the inner corona in rings. As the time of exposure of each ring is controlled by the pins in the commutator barrel, it is expected that practically the whole of the corona, both outer and inner, may be correctly timed on a single plate. Six plates gave a chance to vary the relative exposure in the different rings. But this rather intricate instrument, although its mechanical movements were perfect, suffered a like fate with the others; and it will be interesting to see what it may be competent to do on future occasions.

Of all our apparatus, however, this may be said, that it is provisionally constructed as yet; and it is hoped to try it again during the eclipse of either 1898 or 1900. Both of these are of short duration, only about two minutes, and are to be regarded simply as tentative rehearsals for the great totality of six minutes, in Sumatra, on the 18th of May, 1901.

Amherst College Observatory,
April 1897.

PLATE XXIV.



ELECTRIC COMMUTATOR OF THE AMHERST ECLIPSE EXPEDITION

A METHOD OF CORRECTING THE CURVATURE OF LINES IN THE SPECTROHELIOGRAPH.

By W. H. Wright.

The question of the curvature of lines in the prismatic spectrum has been discussed from time to time, and methods of more or less theoretical validity have been proposed for its correction. Professor Stokes investigated the form of a compound prism giving straight lines, and such prisms have been constructed. In 1874 Mr. Thomas Grubb[1] suggested correction by means of a curved slit. These are so far as the writer knows the only successful methods that have been proposed. By shortening the slit, however, the effects of curvature can be reduced to a minimum and the resulting lines, when magnified, are sensibly straight. But in the case of the spectroheliograph, where a long slit is usually desirable, the curvature becomes noticeable when even moderate dispersion is used, and must be allowed for in the measurement of solar negatives; it would therefore seem desirable to eliminate this distortion if possible. I am unable to learn anything regarding the efficiency of the compound prisms mentioned above, and the plan proposed by Grubb is evidently not applicable to the spectroheliograph. In this instrument, however, only a small part of the spectrum is used at a time, and the peculiar conditions allow special methods.

Before proceeding with the discussion it may be well to call attention to a point involved in the design of that form of spectroheliograph in which the slits are stationary with regard to the prism train, and the Sun and photographic plate move. Let S' (Fig. 1) be the first slit of the instrument and S'' its image on the second slit; further let the side a'' be the image of a', and b'' of b'. Suppose now the Sun's image is caused to move over S' from a' to b'. It is evident from the most elementary considerations that the photographic plate should move from a'' to b'', other-

[1] *Proc. R. Soc.* 22, 308.

wise the image of a point, say in a prominence, would be drawn out into a line on the plate. This line would be perpendicular to the slit, and twice as long as the slit is broad. The resultant blurring would then be a function of the width of the slit, and the maximum width of slit allowable with a system of this sort could be determined from the resolving power of the lens, the grain of the photographic plate, and the efficiency of the instrument. But an inspection of some of the prominence pictures taken at the Kenwood Observatory shows a wealth of detail which demands that every precaution be taken against blurring in future designing of the spectroheliograph. This point is very simple; it is liable to escape attention however, and affects one of the forms of instrument suggested by Mr. Newall.[1]

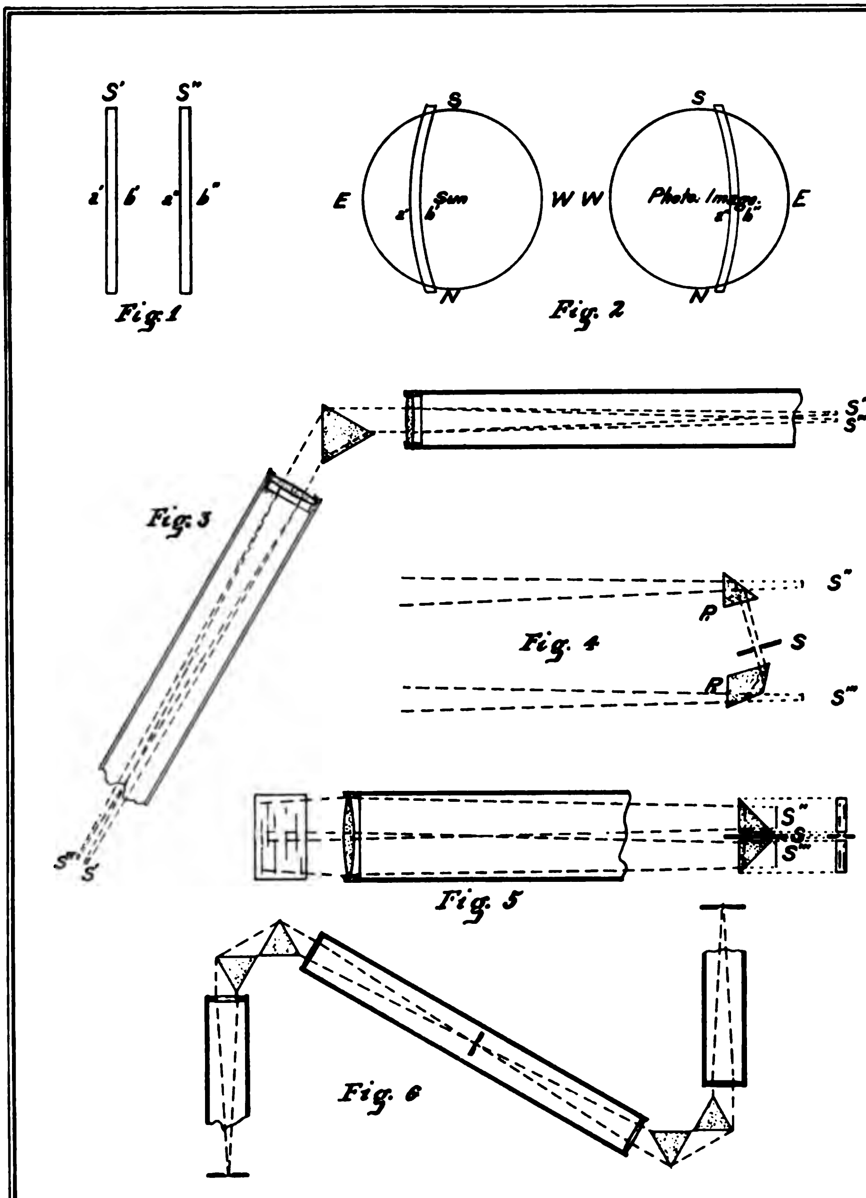
If the slits are so narrow that this astigmatism may be neglected, the distortion due to curvature may be eliminated by the following method suggested by Professor Wadsworth. The front slit is curved so as to be convex toward the edges of the prism (Fig. 2). This will flatten out the image at S'', and the curvature of S' may be so figured that S' and S'' are similar. Now if the Sun travels over S' in the direction a' b' and the plate behind S'' in the direction b'' a'', the slit curvature will be entirely corrected. The resulting negative, however, will be *reversed* when compared with an ordinary one.

The following form of instrument is mentioned with an appreciation of some of its objectionable features, among others its Littrow form, the reflections involved, and the additional absorption attendant upon the return of the light through the prisms. However, it possibly has some advantages to be indicated later and is submitted for what it may be worth.

As before let S' (Fig. 3) be the first slit, and S'' the second. By placing a mirror at S'', we could form an image of S'' at S', *i. e.*, an image of S' on itself. This image would be corrected for curvature due to prisms, and in addition to any distortions due to motions in the line of sight, and haziness caused by non-monochromatism of the light used. However, in this position

[1] *Proc. Camb. Phil. Soc.*, 9, 179.

PLATE XXV.



A METHOD OF CORRECTING THE CURVATURE OF LINES IN THE SPECTROHELIOGRAPH.

our image would avail us little. But by moving S'' to S''' we could form an image S^{iv}, which could be made to satisfy these conditions to within quantities of a negligible order by properly adjusting the line of minimum deviation within the angle $S''\ L''\ S'''$.[1] The shifting of S'' to S''' may be accomplished by reflection from an odd number of mirrors, as in Fig. 4, in which P_1 and P_2 are reflecting prisms, and S a slit, curved to admit the line desired. Instead of moving S'' to S''' we might move it directly down (perpendicular to the paper) by means of the arrangement shown in Fig. 5. This would eliminate one reflection, and would be theoretically perfect, but would necessitate longer prisms, and correspondingly larger lenses. Reflecting prisms might be introduced at S' and S^{iv} as suggested by Mr. Newall, or some other device might be adopted.

As indicated above, this instrument should correct blurring due to hazy lines, and distortions due to line-of-sight motions, when the slit may be opened wide enough to admit the whole of the distorted line. By the use of practically two spectroscopes, as indicated in Fig. 6, the principal objections to the above forms might be disposed of. This whole instrument, it will be noticed, would move in the plane of the paper, the solar image and the photographic plate remaining stationary, as in the spectroheliograph designed by Professor Hale for the late Mr. Raynard. It seems extremely doubtful however, whether the apparent advantages of such a construction would warrant the additional expense and complication.

It will be noticed that the function of the above apparatus is essentially that of a color screen, analogous in some respects to the instrument devised by Professor Wadsworth for cutting out overlapping spectra from a grating spectroscope, and described in this JOURNAL, 3, 169–191.

YERKES OBSERVATORY,
April 1897.

[1] The indulgence of the reader is requested in reference to two oversights in the draughting of the accompanying plate. The first is the omission of the letter L' designating the optical center of the second lens (Fig. 3), the second that of a reversing prism in Fig. 6 between the second slit and the second collimator.

SPECTROGRAPHIC OBSERVATIONS OF MARS IN 1896–7.

By James E. Keeler.

The question whether it is possible to detect the existence of water vapor in the atmosphere of Mars by means of the spectroscope has been the subject of considerable discussion in the last few years. Professor Campbell,[1] as a result of observations made with powerful apparatus under the most favorable conditions, has come to the conclusion that it is not. Mr. Jewell[2] has arrived at the same conclusion from considerations based on his studies of the telluric lines in the solar spectrum at Baltimore, and dismisses the question as one which lies far beyond our means of investigation. Even if it were possible to observe the planet with the apparatus he used for the Sun, the sensitiveness of the method would be insufficient for the purpose. On the other hand, a slight strengthening of the telluric bands in the spectrum of Mars relatively to that of the equally high Moon has been noted by skillful observers on a number of occasions. The extreme difficulty of these observations must not, however, be forgotten.

With regard to the best form of apparatus for such observations there has been some difference of opinion. Mr. Jewell holds that a high resolving power is necessary, while Mr. Campbell considers that high resolving power is not necessary or even desirable. My own experiments[3] lead me to agree with the views of Mr. Campbell. They relate, however, merely to the best means of observation. So far as the main question is concerned, it seems to me that the reasoning which Mr. Jewell applies to the case of an isolated water-vapor line is equally applicable to the lines taken collectively.

[1] *Pub. A. S. P.*, 6, 228. *Ap. J.*, 2, 28.

[2] *Ap. J.*, 3, 255.

[3] *Ap. J.*, 4, 137.

During the winter of 1896–7 I made some experiments in this direction by photographing the spectra of Mars and the Moon on the same plate. The advantages of the method are obvious. Faintness of light can be compensated for by prolonged exposure; the spectra of the two bodies can be given practically equal width and density; they are brought into juxtaposition, so that the comparison is made with the greatest ease and certainty, and a permanent record is secured, which can be consulted as often as desired. On the other hand there are some disadvantages, the chief of which is the great variation of the sensitiveness of the plate with the wave-length in the region where the water-vapor lines occur, while the delicacy of the method, as compared with that of visual observations, is open to doubt Aside from these disadvantages, the precise weight of which could only be ascertained by experiment, there was the very unfavorable condition that the atmosphere at Allegheny almost always contains a large amount of moisture. This, however, equally affects visual observations, and is not to be avoided, especially since the circumstances permit little range in the choice of nights.

The instrument used for the comparison was the Thaw spectroscope[1] mounted on the 13-inch equatorial. The collimator and the camera have each a focal length of 16 inches and an effective aperture of 1.12 inches. A single dense prism was used. It was my intention to use also the train of three prisms, but unfortunately the number of suitable nights was so small that this part of the programme could not be carried out.

Satisfactory photographs were obtained on the nights of December 13 and 16, 1896, and February 13, 1897, when the sky was what passes for clear in Allegheny. The ratio of exposure-times required to produce equal density at the D lines was determined on each evening by a preliminary experiment. On December 16 the exposures were: Moon 16^m, Mars 27^m. Both bodies were at a high altitude. The temperature was 27° and the relative humidity 77 per cent. Several plates were

[1] *A. and A.*, 12, 40.

obtained, on which the spectra of the Moon and Mars were almost exactly equal in width and density. On February 13 the disk of Mars had become so small that it was allowed to drift its own width along the slit, and the exposure was correspondingly increased.

The spectra obtained in the manner described above extend to some distance below the D lines (which are well separated on the plates), and therefore include the water-vapor band in this region, as well as the δ band farther above. But in order to show satisfactorily this extent of spectrum, at a place where the sensitiveness of an orthochromatic plate varies so rapidly with the wave-length, it was necessary to give very full exposure; and therein lies a weakness of the method, for the equalization of density produced by the full exposure also diminishes the contrast between the atmospheric band and the background of continuous spectrum. As a matter of fact, no difference whatever could be found between the spectra of the Moon and Mars, when both bodies were at a high altitude, on any of the plates, and the results of the observations being negative, I have not considered it worth while to describe them in greater detail.

In order to obtain some data for estimating the sensitiveness of the method, comparisons were made in the same way of the high and low Sun, and of the Moon near the zenith and at various lower altitudes. It was found from these comparisons that no differences in the spectra could be detected until the zenith distance of the body at the lower observation was something like 45° or 50°. A slight increase in the strength of the atmospheric bands was suspected at about this point; a decided increase took place only at a much greater zenith distance. It appears therefore that the additional effect of half such an atmosphere as the Earth's might possibly be detected by the method employed. There is every reason to suppose that no effect so great as this can be produced by the atmosphere of Mars.

These results, as far as they go, agree with those obtained visually by Mr. Campbell. I would not, however, draw any

sweeping conclusions from them, since it is quite possible that if a different dispersion had been employed, or even if the plates had been exposed or developed differently, the effectiveness of the method might have been increased.

Such observations evidently require a more favorable climate than that of the eastern United States. It seems to me that Mr. Campbell is justified in attaching great weight to the superior conditions under which his observations were made, *i. e.*, to the dryness of the air at Mt. Hamilton and the elevation of the Observatory above sea level, and also to the observation of the relative strength of the water-vapor lines in the spectrum of Mars at different parts of the disk. A glance at Mr. Jewell's diagram[1] shows that a considerable strengthening of the lines can be expected only at points very near the limb, and hence a large image, obtainable, without sacrifice of light, only with a large telescope, is required. The possibility of making satisfactory comparisons with such an instrument under the best circumstances could probably be correctly estimated only by one actually looking at the spectrum. Personally, I believe this test to be far more reliable than any other that has been proposed.

[1] *Ap. J.*, 1, 314.

ON THE INFLUENCE OF MAGNETISM ON THE NATURE OF THE LIGHT EMITTED BY A SUBSTANCE.[1]

By P. Zeeman.

1. Several years ago, in the course of my measurements concerning the Kerr phenomenon, it occurred to me whether the light of a flame if submitted to the action of magnetism would perhaps undergo any change. The train of reasoning by which I attempted to illustrate to myself the possibility of this is of minor importance at present;[2] at any rate I was induced thereby to try the experiment. With an extemporized apparatus the spectrum of a flame, colored with sodium, placed between the poles of a Ruhmkorff electro-magnet, was looked at. The result was negative. Probably I should not have tried this experiment again so soon had not my attention been drawn some two years ago to the following quotation from Maxwell's sketch of Faraday's life. Here (Maxwell, *Collected Works*, II, 790) we read: "Before we describe this result we may mention that in 1862 he made the relation between magnetism and light the subject of his very last experimental work. He endeavored, but in vain, to detect any change in the lines of the spectrum of a flame when the flame was acted on by a powerful magnet." If a Faraday[3] thought of the possibility of the above-mentioned relation, perhaps it might be yet worth while to try the experiment again with the excellent auxiliaries of spectroscopy of the present time, as I am not aware that it has been done by others.[4] I will take the liberty of stating briefly to the readers of the *Philosophical Magazine* the results I have obtained up till now.

2. The electro-magnet used was one made by Ruhmkorff and

[1] *Philosophical Magazine* [5], 43, March 1897, p. 226.

[2] *Cf.* §§ 15 and 16.

[3] See appendix for Faraday's own description of the experiment.

[4] See appendix.

of medium size. The magnetizing current furnished by accumulators was in most of the cases 27 amperes, and could be raised to 35 amperes. The light used was analyzed by a Rowland grating, with a radius of 10 feet and with 14,938 lines per inch. The first spectrum was used, and observed with a micrometer eyepiece with a vertical cross-wire. An accurately adjustable slit is placed near the source of light under the influence of magnetism.

3. Between the paraboloidal poles of an electro-magnet the middle part of the flame from a Bunsen burner was placed. A piece of asbestos impregnated with common salt was put in the flame in such a manner that the two D lines were seen as narrow and sharply defined lines on the dark ground. The distance between the poles was about 7^{mm}. If the current was put on, the two D lines were distinctly widened. If the current was cut off they returned to their original position. The appearing and disappearing of the widening was simultaneous with the putting on and off of the current. The experiment could be repeated an indefinite number of times.

4. The flame of the Bunsen was next interchanged with a flame of coal gas fed with oxygen. In the same manner as in § 3 asbestos soaked with common salt was introduced into the flame. It ascended vertically between the poles. If the current was put on again the D lines were widened, becoming perhaps three or four times their former width.

5. With the red lines of lithium, used as carbonate, wholly analogous phenomena were observed.

6. Possibly the observed phenomena (§§ 3, 4, 5) will be regarded as nothing of any consequence. One may reason in this manner: widening of the lines of the spectrum of an incandescent vapor is caused by increasing the density of the radiating substance and by increasing the temperature.[1] Now, under the influence of the magnet, the outline of the flame is undoubtedly changed (as is easily seen), hence the temperature and possibly also the density of the vapor is changed. Hence one

[1] *Cf.* however, also Pringsheim (*Wied. Ann.*, 45, 457, 1892).

might be inclined to account in this manner for the phenomenon.

7. Another experiment is not so easily explained. A tube of porcelain, glazed inside and outside, is placed horizontally between the poles with its axis perpendicular to the line joining the poles. The inner diameter of the tube is 18^{mm}, the outer one 22^{mm}. The length of the tube is 15^{cm}. Caps are screwed on at each end of the tube;[1] these caps are closed by plates of parallel glass at one end and are surrounded by little water-jackets. In this manner, by means of a current of water, the copper caps and the glass plates may be kept sufficiently cool while the porcelain tube is rendered incandescent. In the neighborhood of the glass plates, side tubes provided with taps are fastened to the copper caps. With a large Bunsen burner the tube could be made incandescent over a length of 8^{cm}. The light of an electric lamp, placed sideways at about two meters from the electro-magnet, in order to avoid disturbing action on the arc, was made to pass through the tube by means of a metallic mirror. The spectrum of the arc was formed by means of the grating. With the eyepiece the D lines are focused. This may be done very accurately, as in the center of the bright D lines the narrow reversed lines are often seen. Now a piece of sodium was introduced into the tube. The Bunsen flame is ignited and the temperature begins to rise. A colored vapor soon begins to fill the tube, being at first of a violet, then of a blue and green color, and at last quite invisible to the naked eye. The absorption soon diminishes as the temperature is increased. The absorption is especially great in the neighborhood of the D lines. At last the two dark D lines are visible. At this moment the poles of the electro-magnet are pushed close to the tube, their distance now being about 24^{mm}. The absorption lines now are rather sharp over the greater part of their length. At the top they are thicker, where the spectrum of the lower, denser vapors was observed. Immediately after

[1] PRINGSHEIM uses similar tubes in his investigation concerning the radiation of gases, *l. c.*, p. 430.

the closing of the current the lines *widen* and are seemingly *blacker;* if the current is cut off they immediately recover their initial sharpness. The experiment could be repeated several times, till all the sodium had disappeared. The disappearance of the sodium is chiefly to be attributed to the chemical action between it and the glazing of the tube. For further experiments, therefore, unglazed tubes were used.

8. One may perhaps try to account for the last experiment (§ 7) in this direction: it is true that the tube used was not of the same temperature at the top and at the bottom; further, it appears from the shape of the D lines (§ 7) that the density of the vapor of sodium is different at different heights. Hence certainly convection currents caused by difference of temperature between the top and bottom were present. Under certain plausible suppositions one may calculate that, by the putting on of the electro-magnet, differences of pressure are originated in the tube of the same order of magnitude as those caused by the difference of temperature. Hence the magnetization will push *e. g.*, the denser layer at the bottom in the direction of the axis of the tube. The lines become widened. For their width at a given height is chiefly determined by the number of incandescent particles at that height in the direction of the axis of the tube. Although this explanation still leaves some difficulties, certainly something may be said for it.

9. The explanation of the widening of the lines attempted in § 8 is no longer applicable to the following variation of the experiment, in which an unglazed tube is used. The inner diameter of the tube, about 1^{mm} thick, was 10^{mm}. The poles of the electro-magnet could be moved till the distance was 14^{mm}. The tube was now heated by means of the blowpipe instead of with the Bunsen burner, and became in the middle part white hot. The blowpipe and the smaller diameter of the tube make it easier to bring the upper and lower parts to the same temperature. This is now higher than before (§ 7) and the sodium lines remain visible continuously.[1] One can now wait till the

[1] PRINGSHEIM, *l. c.*, p. 456.

density of the sodium vapor is the same at various heights. By rotating the tube continuously round its axis I have still further promoted this. The absorption lines now are equally broad from the top to the bottom. When the electro-magnet was put on, the absorption lines immediately widened along their whole length. Now the explanation in the manner of § 8 fails.

10. I should like to have studied the influence of magnetism on the spectrum of a solid. Oxide of erbium has, as was found by Bunsen or Bahr, the remarkable property of giving by incandescence a spectrum with bright lines. With the dispersion used, however, the edges of these lines were too indistinct to serve my purpose.

11. The different experiments from §§ 3 to 9 make it more and more probable that the absorption—and hence also the emission lines of an incandescent vapor are widened by the action of magnetism. Now if this is really the case, then by the action of magnetism on the free vibrations of the atoms, which are the cause of the line spectrum, other vibrations of changed period must be superposed. That it is really inevitable to admit this specific action of magnetism is proved, I think, by the rest of the present paper.

12. From the representation I had formed to myself of the nature of the forces acting in the magnetic field on the atoms, it seemed to me to follow that with a band spectrum and with external magnetic forces the phenomenon I had found with a line spectrum would not occur.

It is, however, very probable that the difference between a band and a line spectrum is not of a quantitative but of a qualitative kind.[1] In the case of a band spectrum the molecules are complicated; in the case of a line spectrum the widely separated molecules contain but a few atoms. Further investigation has shown that the representation I had formed of the cause of the widening in the case of a line spectrum in the main was really true.

13. A glass tube, closed at both ends by glass plates with

[1] KAYSER in Winklemann's *Handbuch*, II, 1, p. 421.

parallel faces and containing a piece of iodine, was placed between the poles of the Ruhmkorff electro-magnet in the same manner as the tube of porcelain in § 7. A small flame under the tube vaporized the iodine, the violet vapor filling the tube.

By means of electric light the absorption spectrum could be examined. As the temperature is low this is the band spectrum. With the high dispersion used, there are seen in the bands a very great number of fine dark lines. If the current around the magnet is closed, *no* change in the dark lines is observed, which is contrary to the result of the experiments with sodium vapor.

The absence of the phenomenon in this case supports the explanation, that even in the first experiment, with sodium vapor (§ 7) the convection currents had no influence. For in the case now considered, the convection currents originated by magnetism, which I believed to be possible in that case, apparently are insufficient to cause a change of the spectrum; yet, though I could not see it in the appearance of the absorption lines (*cf.* § 7), the band spectrum is, like the line spectrum, very sensible to changes of density and of temperature.

14. Although the means at my disposal did not enable me to execute more than a preliminary approximate measurement, I yet thought it of importance to determine approximately the value of the magnetic change of the period.

The widening of the sodium lines to both sides amounted to about $\frac{1}{40}$ of the distance between the said lines, the intensity of the magnetic field being about 10^4 C. G. S. units. Hence follows a positive and negative magnetic change of $\frac{1}{40000}$ of the period.

15. The train of reasoning mentioned in (1), by which I was induced to search after an influence of magnetism, was at first the following: If the hypothesis is true that in a magnetic field a rotary motion of the ether is going on, the axis of rotation being in the direction of the magnetic forces (Kelvin and Maxwell), and if the radiation of light may be imagined as caused by the motion of the atoms, relative to the center of mass of the molecule, revolving in all kinds of orbits, suppose for simplicity, circles; then the period, or what comes to the same, the

time of describing the circumference of these circles, will be determined by the forces acting between the atoms, and then deviations of the period to both sides will occur through the influence of the perturbing forces between ether and atoms. The sign of the deviation, of course, will be determined by the direction of motion, as seen from along the lines of force. The deviation will be the greater the nearer the plane of the circle approximates to a position perpendicular to the lines of force.

16. Somewhat later I elucidated the subject by representing to myself the influence exercised on the period of a vibrating system if this is linked together with another in rapid rotary motion. Lord Kelvin (now forty years ago)[1] gave the solution of the following problem: Let the two ends of a cord of any length be attached to two points at the ends of a horizontal arm made to rotate round a vertical axis through its middle point at a constant angular velocity, and let a second cord bearing a material point be attached to the middle of the first cord. The motion now is investigated in the case when the point is infinitely little disturbed from its position of equilibrium. With great angular velocity the solution becomes rather simple. Circular vibrations of the point in contrary directions have slightly different periods. If for the double pendulum we substitute a luminiferous atom, and for the rotating arm the rotational motion about the magnetic lines of force, the relation of the mechanical problem to our case will be clear.

It need not be proved that the above-mentioned considerations are at most of any value as indications of somewhat analogous cases. I communicate them, however, because they were the first motive of my experiments.

17. A real explanation of the magnetic change of the period seemed to me to follow from Professor Lorentz's theory.[2]

In this theory it is assumed that in all bodies small electri-

[1] *Proc. R. Soc.*, 1856.

[2] LORENTZ, *La Théorie électromagnétique de Maxwell.* Leyde, 1892; and *Versuch einer Theorie der electrischen und optischen Erscheinungen in bewegten Körpern.* Leyden, 1895.

cally charged particles with a definite mass are present, that all electric phenomena are dependent upon the configuration and motion of these "ions," and that light vibrations are vibrations of these ions. Then the charge, configuration, and motion of the ions completely determine the state of the ether. The said ion, moving in a magnetic field, experiences mechanical forces of the kind above mentioned, and these must explain the variation of the period. Professor Lorentz, to whom I communicated these considerations, at once kindly informed me of the manner in which, according to his theory, the motion of an ion in a magnetic field is to be calculated, and pointed out to me that, if the explanation following from his theory be true, the edges of the lines of the spectrum ought to be circularly polarized. The amount of widening might then be used to determine the ratio between charge and mass, to be attributed in this theory to a particle giving out the vibrations of light.

The above-mentioned extremely remarkable conclusion of Professor Lorentz relating to the state of polarization in the magnetically widened lines I have found to be fully confirmed by experiment (§ 20).

18. We shall now proceed to establish the equations of motion of a vibrating ion, when it is moving in the plane of (x, y) in a uniform magnetic field in which the magnetic force is everywhere parallel to the axis of z and equal to H. The axes are chosen so that if x is drawn to the east, y to the north, z is upwards. Let e be the charge (in electro-magnetic measure) of the positively charged ion, m its mass. The equations of relative motion then are:

$$\left.\begin{aligned} m\frac{d^2x}{dt^2} &= -k^2x + eH\frac{dy}{dt} \\ m\frac{d^2y}{dt^2} &= -k^2y - eH\frac{dx}{dt} \end{aligned}\right\} \qquad (1)^{1}$$

The first term of the second member expresses the elastic force drawing back the ion to its position of equilibrium; the

[1] These equations are like those of the Foucault pendulum, and of course lead to similar results.

second term gives the mechanical force due to the magnetic field. They are satisfied by

$$\left.\begin{aligned} x &= \alpha e^{st} \\ y &= \beta e^{st} \end{aligned}\right\} \tag{2}$$

provided that

$$\left.\begin{aligned} m s^2 \alpha &= -k^2 \alpha + e H s \beta \\ m s^2 \beta &= -k^2 \beta - e H s \alpha \end{aligned}\right\} \tag{3}$$

where m, k, e are to be regarded as known quantities.

For us the period T is particularly interesting. If $H = 0$, it follows from (3) that

$$S = i\frac{k}{\sqrt{m}} = i\frac{2\pi}{T}$$

or

$$T = \frac{2\pi\sqrt{m}}{k}. \tag{4}$$

If H is not 0, it follows from (3) approximately that

$$S = i\frac{k}{\sqrt{m}}\left(1 \mp \frac{eH}{2k\sqrt{m}}\right).$$

Putting T' for the period in this case, we have

$$T' = \frac{2\pi\sqrt{m}}{k}\left(1 \pm \frac{eH}{2k\sqrt{m}}\right). \tag{5}$$

Hence the ratio of the change of period to the original period becomes

$$\frac{eH}{2k\sqrt{m}} = \frac{e}{m} \cdot \frac{HT}{4\pi}. \tag{6}$$

A particular solution of (1) is that representing the motion of the ions in circles. If revolving in the positive direction (viz., in the direction of the hands of a watch for an observer standing at the side towards which the lines of force are running) the period is somewhat less than if revolving in the negative direction. The period in the first case is determined by the value of (5) with the minus sign, in the second with the plus.

The general solution of (1) shows that the ions describe, besides circles, also slowly rotating elliptical orbits. In the general case, the original motion of the ion having an arbitrary position in space, it is perfectly clear that the projection of the

motion in the plane of (x, y) has the same character. The motion resolved in the direction of the axis of z is a simple harmonic motion, independent of and not disturbing the one in the plane of (x, y), and hence one not influenced by the magnetic forces. Of course, the consideration of the motion of an ion now given is only to be regarded as the very first sketch of the theory of luminiferous motions.

19. Imagine an observer looking at a flame placed in a magnetic field in a direction such that the lines of force run towards or from him.

Let us suppose that the said observer could see the very ions of § 18 as they are revolving; then the following will be remarked: There are some ions moving in circles and hence emitting circularly polarized light; if the motion is round in the positive direction the period will, for instance, be longer than with no magnetic field; if in the negative direction, shorter. There will also be ions seemingly stationary and really moving parallel to the lines of force with unaltered period. In the third place there are ions which seem to move in rotating elliptical orbits.

If one desires to know the state of the ether originated by the moving ions one may use the following rule, deduced by Professor Lorentz from the general theory: Let us suppose that in a molecule an ion P, of which the position of equilibrium is P_0, has two or more motions *at the same time*, viz., let the vector P_0P always be obtained by adding the vectors P_0P which should occur in each of the component motions at that moment; then the state in the ether at a very great distance in comparison with P_0P will be obtained by superposing the states which would occur in the two cases taken separately.

Hence it follows in the first place that a circular motion of an ion gives circularly polarized light to points on the axis of the circle.

Further, one may choose instead of the above-considered elliptical orbits a resolution more suited to our purpose. One may resolve the motion of the ion, existing before the putting

on of the magnetic force, into a rectilinear harmonic motion parallel to the axis of z and two circular (right-handed and left-handed) motions in the plane of (x, y).

The first remains unchanged under the influence of the magnetic force, the periods of the last are changed.

By the action of the grating the vibrations originated by the motion of the ions are sorted according to the period, and hence the complete motion is broken up into three groups. The line will be a triplet. At any rate one may expect that the line of the spectrum will be wider than in the absence of the magnetic field, and that the edges will give out circularly-polarized light.[1]

20. A confirmation of the last conclusion may be certainly taken as a confirmation of the guiding idea of Professor Lorentz's theory. To decide this point by experiment, the electro-magnet of § 2, but now with pierced poles, was placed so that the axes of the holes were in the same straight line with the center of the grating. The sodium lines were observed with an eyepiece with a vertical cross-wire. Between the grating and the eyepiece were placed the quarter-undulation plate and Nicol which I formerly used in my investigation of the light normally reflected from a polarly magnetized iron mirror.[2]

The plate and the Nicol were placed relatively in such a manner that right-handed circularly polarized light was quenched. Now according to the preceding the widened line must at one edge be right-handed circularly polarized, at the other edge left-handed. By a rotation of the analyzer over 90° the light that was first extinguished will be transmitted, and *vice versa*. Or, if first the right edge of the line is visible in the apparatus, a reversal of the direction of the current makes the left edge visible. The cross-wire of the eyepiece was set in the bright line. At the reversal of the current the visible line moved! This experiment could be repeated any number of times.

[1] I saw afterward that Stoney, *Trans. R. Soc., Dublin*, IV, endeavors to explain the existence of doublets and triplets in a spectrum by the rotation of the elliptical orbits of the "electrons" under the influence of perturbing forces.

[2] ZEEMAN, *Communications of the Leyden Laboratory*, No. 15.

21. A small variation of the preceding experiment is the following: With unchanged position of the quarter-wave plate the analyzer is turned round. The widened line is then, during one revolution, twice wide and twice fine.

22. The electro-magnet was turned 90° in a horizontal plane from the position of § 20, the lines of force now being perpendicular to the line joining the slit with the grating. The edges of the widened line now appeared to be plane polarized, at least in so far as the present apparatus permitted to see, the plane of polarization being perpendicular to the line of the spectrum. This phenomenon is at once evident from the consideration § 19. The circular orbits of the ions being perpendicular to the lines of force are now seen on their edges.

23. The experiments 20 to 22 may be regarded as a proof that the light vibrations are caused by the motion of ions, as introduced by Professor Lorentz in his theory of electricity. From the measured widening (§ 14) by means of relation (6), the ratio $e : m$ may now be deduced. It thus appears that $e : m$ is of the order of magnitude 10^7 electro-magnetic C. G. S. units. Of course this result from theory is only to be considered as a first approximation.

24. It may be deduced from the experiment of § 20 whether the positive or the negative ion revolves.

If the lines of force were running towards the gratings, the right-handed circularly polarized rays appeared to have the smaller period. Hence in connection with § 18 it follows that the positive ions revolve, or at least describe the greater orbit.

25. Now that the magnetization of the lines of a spectrum can be interpreted in the light of the theory of Professor Lorentz, the further consideration of it becomes specially attractive. A series of further questions already present themselves. It seems very promising to investigate the motion of the ions for various substances, under varying circumstances of temperature and pressure, with varying intensities of the magnetization. Further inquiry must also decide as to how far the strong mag-

netic forces existing according to some at the surface of the Sun may change its spectrum.

The experiments described have been made in the physical laboratory at Leyden, to the Director of which, Professor Kammerlingh Onnes, I am under great obligations for continuous interest in the present subject.

AMSTERDAM, January 1897.

APPENDIX.

Since the publication of my original paper in the *Proceedings* of the Academy at Amsterdam, and while the present paper was in the press, I have become acquainted with two attempts, till now unknown to me, in the same direction, and also with the original account of Faraday's experiment referred to in § 1. The last is to be found in Faraday's *Life* by Dr. Bence Jones, II, 449 (1870) and as it is extremely remarkable I will reprint it here:

1862 was the last year of experimental research. Steinheil's apparatus for producing the spectrum of different substances gave a new method by which the action of magnetic poles upon light could be tried. In January he made himself familiar with the apparatus, and then he tried the action of the great magnet on the spectrum of chloride of sodium, chloride of barium, chloride of strontium, and chloride of lithium.

On March 12 he writes:

Apparatus as on last day (January 28) but only ten pairs of voltaic battery for the electro-magnet.

The colorless gas flame ascended between the poles of the magnet, and the salts of sodium, lithium, etc., were used to give color. A Nicol's polarizer was placed just before the intense magnetic field, and an analyzer at the other extreme of the apparatus. Then the electro-magnet was made, and unmade, but not the slightest trace of effect on or change in the lines in the spectrum was observed in any position of polarizer or analyzer.

Two other pierced poles were adjusted at the magnet, the colored flame established between them, and only that ray taken up by the optic apparatus which came to it along the axis of the poles, *i. e.*, in the magnetic axis, or line of magnetic force. Then the electro-magnet was excited and rendered

neutral, but not the slightest effect on the polarized or unpolarized ray was observed.

This was the last experimental research that Faraday made.

In 1875 we have a paper by Professor Tait, who has kindly sent me a copy, "On a Possible Influence of Magnetism on the Absorption of Light, and some correlated subjects" (*Proc. R. Soc. Edinburgh*, session 1875–6, p. 118). Professor Tait remarks that a paper by Professor Forbes read at the Society, and some remarks upon it by Maxwell, have recalled to him an experiment tried by him several times, but which hitherto has led to no result. Then the paper proceeds:

The idea is briefly this: The explanation of Faraday's rotation of the plane of polarization of light by a transparent diamagnetic requires, as shown by Thomson, molecular rotation of the luminiferous medium. The plane-polarized ray is broken up, while in the medium, into its circularly polarized components, one of which rotates with the ether so as to have its period accelerated, the other against it in a retarded period. Now, suppose the medium to absorb one definite wave-length only, then—if the absorption is not interfered with by the magnetic action—the portion absorbed in one ray will be of a shorter, in the other of a longer, period than if there had been no magnetic force; and thus, what was originally a single dark absorption line might become a double line, the components being less dark than the single one.

Hence here the idea is perfectly clearly expressed of the experiment, tried in vain; an idea closely akin to that of § 15 above, both being in fact founded on Kelvin's theory of the molecular rotation of the luminiferous medium, though not directly applicable to the experiment of § 9, in which case the lines of magnetic force are perpendicular to the axis of the tube.

In the second place I have to mention two papers by the late M. Fievez, to which attention has been drawn by M. van Aubel, in a letter to Professor Onnes and intended for communication to the Academy of Sciences, Amsterdam. Professor Onnes read the letter at the January meeting, and made at the same time some explanatory remarks of which in the following I make free and extensive use. The papers referred to are: M. Fievez, "De l'Influence du Magnétisme sur les Caractères

des Raies spectrales" (*Bulletin de l'Acad. des Sciences de Belgique*, 3[e] série, tome 9, 381, 1885); and Fievez, "Essai sur l'Origine des Raies de Fraunhofer, en rapport avec la Constitution du Soleil" (*l. c.*, 3[e] série, tome 12, 30, 1886). Here experiments are described as in §§ 4 and 13 of the present paper. Nothing, however, is observed about the widening of the absorption lines, nor about the polarization of the emitted light. The results obtained by M. Fievez merit careful attention and consideration. He has observed with a flame in a magnetic field not only widening but reversal and double reversal of the lines of the spectrum, the lines at the same time becoming more brilliant. Unfortunately quantitative details are not given. The facts observed in some cases by Fievez are qualitatively not in accordance with my observations or what is to be deduced from my results. Hence even in the cases where the results are qualitatively in accordance, the question remains whether Fievez has observed *the same phenomenon*. The field used by Fievez seems to have been more intense than the one I had at my disposal. Is it possible perhaps to account in this manner for the "double renversement (c'est-à-dire l'apparition d'une raie brillante au milieu de la raie noire élargie)?" I think the answer must be in the negative. For, arguing from § 19, a line must widen, or else, the field being very intense, become a triplet. We cannot but understand from Fievez's description of the experiment that the light was emitted perpendicular to the lines of force. Now the double reversed line of Fievez is not the triplet to be expected from theory, for it is expressly stated by Fievez that the line experimented upon is not the simple line of the spectrum, but one previously widened and reversed (by some agency independent of magnetism). By the action of magnetism a brilliant line in the center of the black line appears. Hence perhaps one may interpret the case of double reversal as a direct action of magnetism, but then only as a doubling of the absorption line and not as a division of the original lines into three parts. As the application of Lorentz's theory given in § 18 is confessedly only a very first sketch,

further theoretical and experimental evidence is wanted before we are to able to decide whether in the experiment of Fievez a specific action of magnetism on light or perturbing circumstances have been prevalent. Indeed one may make the same objection to M. Fievez's experiment as I myself have made to my own analogous experiment in § 6.

The whole of the phenomena observed by Fievez can readily be attributed to a change of temperature by the well-known actions of the field upon the flame (change in its direction or outline, magnetic convection, etc.); and the last sentence of his paper states that "les phénomènes qui se manifestent sous l'action du magétisme sont identiquement les mêmes que ceux produits par une élévation de température." The negative result obtained by Fievez with absorption spectra would without further consideration (as in § 12) point in the same direction. The inference to be drawn from Fievez's experiments alone would rather be, I think, that the temperature of the flame is changed in his experiments than that a specific action of magnetism on the emission and absorption of light exists. By experiments already in progress I hope to settle the dubious points.

Summarizing we may say: Had the experiments of Fievez come to my knowledge they would have been a motive for me to further investigation, Fievez not having prosecuted his inquiry up to a decisive result. At least at present it remains even doubtful whether the phenomenon observed by Fievez with a magnetized flame is really to be attributed to ***the specific action of the magnetic field on the period of the vibrations of light***, which I have found and undoubtedly proved by the experimental confirmation of Lorentz's predictions.

AMSTERDAM, February 1897.

Minor Contributions and Notes.

CURVATURE OF THE SPECTRAL LINES.[1]

In Scheiner's *Spektralanalyse der Gestirne* is given the equation of the curve of the lines as seen in a prism spectroscope. There is no demonstration offered but the reader is referred to a paper by Ditscheiner.

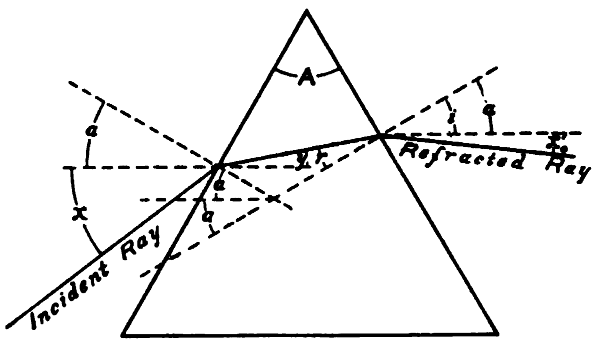


Fig. 1.

As this paper is inaccessible to a great many interested in spectroscopic work, and as this equation can be deduced in a very simple manner, I venture to offer my own demonstration as I give it to my students in astrophysics.

Let h = the angle any incident ray makes with the principal section of the prism.

x = the angle its projection on the principal section makes with the bisectrix of the angle between the normals to the two faces of the prism.

x' = the same for the refracted ray.

y = the same for the ray inside the prism.

a = half the angle between the normals to the faces of the prism.

n = the index of refraction.

[1] Since the above was written my attention has been called to a paper on the same subject, by Mr. W. H. M. Christie, published in the *Monthly Notices* for March, 1874. His method of proof is, however, somewhat different from mine and his final results are not in quite the same form as those given in Scheiner.

Then we have from Mascart, *Traite d'Optique*, Tome I., page 85,

$$\sin(a+y) = \frac{\cos h}{\sqrt{n^2 - \sin^2 h}} \sin(a+x) = B \sin(a+x) \qquad (1)$$

$$\sin(a-y) = \frac{\cos h}{\sqrt{n^2 - \sin^2 h}} \sin(a+x') = B \sin(a+x') \qquad (2)$$

add and subtract (1) and (2)

$$2 \sin(a) \cos(y) = B [\sin(a+x) + \sin(a+x')] \qquad (3)$$

$$2 \cos(a) \sin(y) = B [\sin(a+x) - \sin(a+x')] \qquad (4)$$

Square (3) and (4), divide by $\sin^2(a)$ and $\cos^2(a)$ respectively, add and reduce:

$$\left.\begin{aligned} \sin^2(2a) = B^2 \{&[\sin^2(a+x) + \sin^2(a+x')] \\ &+ 2\cos(2a)\sin(a+x)\sin(a+x')\} \end{aligned}\right\} \qquad (5)$$

Substitute the value of B in (5),

$$\left.\begin{aligned} \frac{\sin^2(2a)[n^2 - \sin^2 h]}{\cos^2 h} &= \sin^2(a+x) + \sin^2(a+x') \\ &+ 2\cos(2a)\sin(a+x)\sin(a+x'). \end{aligned}\right\} \qquad (6)$$

It is evident that with a straight slit for all values of h, x is constant, but x' varies. When $h = 0$ let $x' = x_0'$. When $h = 0$ (6) becomes

$$\left.\begin{aligned} n^2 \sin^2(2a) &= \sin^2(a+x) + \sin^2(a+x_0') \\ &+ 2\cos(2a)\sin(a+x)\sin(a+x_0'). \end{aligned}\right\} \qquad (7)$$

Subtract (7) from (6),

$$\left.\begin{aligned} &\sin^2(2a)\left[\frac{n^2 - \sin^2 h}{\cos^2 h} - n^2\right] = \sin^2(a+x') - \sin^2(a+x_0') \\ &+ 2\cos(2a)\sin(a+x)[\sin(a+x') - \sin(a+x_0')] \\ &= [\sin(a+x') - \sin(a+x_0')][\sin(a+x') \\ &+ \sin(a+x_0') + 2\cos(2a)\sin(a+x)] \end{aligned}\right\} (8)$$

$$\left.\begin{aligned} &= 2\cos\left(a + \frac{x' + x_0'}{2}\right)\sin\left(\frac{x' - x_0'}{2}\right) \\ &\left[2\sin\left(a + \frac{x' + x_0'}{2}\right)\cos\frac{x' - x_0'}{2} + 2\cos(2a)\sin(a+x)\right] \end{aligned}\right\} (9)$$

For small values of h, we may put $\cos\frac{x' - x_0'}{2} = 1$, $a + \frac{x' + x_0'}{2} = a + x_0'$, etc.

$$\left.\begin{aligned} &\sin^2(2a)\left[\frac{n^2 - \sin^2 h}{\cos^2 h} - n^2\right] = 4\cos(a + x_0') \\ &\left[\sin(a+x_0') + \cos(2a)\sin(a+x)\right]\sin\frac{x' - x_0'}{2}\,. \end{aligned}\right\} (10)$$

When h is small the left hand side reduces to $(n^2 - 1) \sin^2 (2a) \sin^2 (h)$.

Let r = the angle between the ray inside the prism and normal to the second face of the prism.

i = the angle between the normal to the second face and last direc tion of the ray.

A = prism angle, then $i = (a + x_0')$ $2a = A$ $\sin (a + x) = n \sin (A - r)$. In the notation of Scheiner $\sin (h) = \frac{Z}{f} = h$ nearly, $x' - x_0' = -\frac{X}{f}$, collimator and observing telescope having the same focal length. Making these substitutions (10) becomes, since $\sin \frac{X}{f} = \frac{X}{f}$, nearly,

$$(n^2 - 1) \sin^2 A \left(\frac{Z^2}{f^2}\right) = -2 \cos (i) [\sin (i) + n \cos (A) \sin (A - r)] \frac{X}{f},$$

since $\sin (i) = n \sin (r)$.

$$Z^2 = -\frac{2fn \cos (i) [\sin (r) + \cos (A) \sin (A - r)] X}{(n^2 - 1) \sin^2 (A)}$$

$$Z^2 = -\frac{2nf \cos (i) \cos (A - r)}{(n^2 - 1) \sin A} \cdot X$$

which is Scheiner's formula.

H. C. LORD.

EMERSON MCMILLIN OBSERVATORY.

ERRATA.

In Dr. Brace's "Note on Steady Liquid Surfaces" in this JOURNAL, 5, March 1897, p. 215, line 9, for 1" read 0.'1.

In Professor Campbell's article in this JOURNAL, 5, April 1897, p. 236, line 12, for Oct. 22, *1895* read Oct. 22, *1896*.

STARS HAVING PECULIAR SPECTRA.[1]

A LIST of stars having peculiar spectra is given in the annexed table. With four exceptions noted below they were all discovered by Mrs. Fleming in her regular examination of the Draper Memorial photographs. The designation of the star, its approximate right ascension and declination for 1900, its catalogue magnitude, and a brief description of its photographic spectrum are given in the successive columns of the table. When the object is not a catalogue star its

[1] Harvard College Observatory, *Circular No. 17.*

position as derived from a photograph, is given in the notes following the table.

Designation	R. A. 1900	Dec. 1900	Mag.	Description
	h m			
....	0 25.6	−46° 58′	..	Type III. Hydrogen lines bright. Variable.
....	5 35.1	−69 52	..	Gaseous Nebula. Gal. long. 247° 08′, lat. −31° 43′.
A.G.C. 6633	5 36.0	−34 8	2.5	*Hβ* bright, superposed on broad dark line. α Columbae.
A.G.C. 9313	7 14.5	−24 47	4.6	Peculiar. 30 Can. Maj. Resembles ζ Puppis.
A.G.C. 10182	7 43.9	−25 42	5.3	*Hβ* bright. o Puppis.
−41°3911	8 10.8	−41 24	10	*Hβ*, Hγ, Hδ, and Hζ bright. Resembles η Carinae.
A.G.C. 12465	9 4.8	−70 8	5.2	*Hβ* bright, superposed on broad dark line. E Carinae.
A.G.C. 17542	12 48.8	−56 37	5.5	*Hβ* bright. Companion to μ Crucis.
....	13 31.1	−55 58	..	Peculiar. Variable.
A.G.C. 19273	14 8.0	−56 37	5.6	*Hβ* bright.
....	16 21.1	−43 26	..	Type IV.
A.G.C. 22640	16 39.2	−46 54	7.4	Bright band, wave-length about 4700.
−36°11341	17 7.0	−37 0	9.1	Gaseous Nebula. Gal. long. 317° 13′. lat. −0° 45′.
....	17 11.6	−45 52	..	Type IV.
−7°4689	18 39.1	− 7 12	8.2	*Hβ* bright.
−7°5141	19 55.7	− 7 39	9.8	Type IV.
....	20 8.5	−44 43	..	Peculiar. Variable.
A.G.C. 29191	21 11.5	−39 15	7.3	Peculiar.
A.G.C. 31272	22 55.0	−23 4	8	Peculiar.

The position of the first star is R. A.$=0^h\ 24^m\ 23^s.9$, Dec.$-47°\ 6'\ 3''$ (1875). Dr. De Lisle Stewart, at Arequipa, called attention to the spectrum of this star on a plate taken with the Bruce 24-inch telescope, adding the remark "bright lines (hydrogen?)." On examination by Mrs. Fleming it proved to be variable, having a spectrum of the type characteristic of such stars.

The position of the second object which is in the larger Magellanic Cloud is R. A.$=5^h\ 35^m\ 20^s.0$, Dec.$-69°\ 52'\ 51''$ (1875).

The bright band in ζ Puppis having wave-length 4688 is dark in the spectrum of 30 Canis Majoris. This spectrum, like that of the adjacent star, 29 Canis Majoris, was found by the writer to contain the additional hydrogen lines having wave-lengths 3925, 4027, 4202, and 4544.

The bright line in the spectrum of o Puppis was found independently by Dr. Stewart.

The position of the ninth star is R. A. $= 13^h\ 29^m\ 32^s.3$, Dec. $-55°\ 50'\ 10''$ (1875). The spectrum of this star may resemble that of ζ Puppis, since it contains two bright lines which may coincide with the lines having wave-lengths 4633 and 4688 in the spectrum of that star. ζ Puppis, 29 Canis Majoris, 30 Canis Majoris, and this star may form a subdivision of Type V. All of these stars are near the central line of the Milky Way.

The bright line in the spectrum of *A. G. C.* 19273 was found by Miss A. J. Cannon.

The position of the eleventh star is R. A. $= 16^h\ 19^m\ 15^s.9$, Dec. $-43°\ 22'\ 49''$ (1875).

The thirteenth object, $-36°$ 11341, is *N. G. C.* 6302.

The position of the fourteenth star is R. A. $= 17^h\ 9^m\ 46^s.1$, Dec. $-45°\ 49'\ 44''$ (1875).

The position of the seventeenth star is R. A. $= 20^h\ 6^m\ 45^s.2$, Dec. $-44°\ 46'\ 59''$ (1875). Dr. Stewart noted "bright line star (faint)" on a Bruce photograph. An examination by Mrs. Fleming shows that the star is variable and that the spectrum is peculiar.

DISTRIBUTION OF STARS IN CLUSTERS.

Professor Bailey has recently made a count of the stars in the vicinity of several clusters. An enlargement was made of a photograph of the Pleiades taken with the Bruce telescope and having an exposure of six hours. A region 2° square, with η Tauri (Alcyone) in the center was divided into 144 smaller squares, each 10 on a side. The stars in each of these squares were then counted. The total number thus found was 3972, an average of 28 in each square. The 42 squares including the brighter stars in the group contain 1012 stars, an average of 24 per square. It therefore appears that the total number of stars in the region of the Pleiades is actually less than that in adjacent portions of the sky, of equal area, and it is much less than the corresponding number in many parts of the Milky Way. The Pleiades must, therefore, be regarded, first as a group consisting of comparatively bright stars; secondly, if we omit the bright stars, the number of faint stars will be much less than in the adjacent portions of the sky. This absorption of the faint stars is probably due to the nebulosity surrounding this group. A similar absence of faint stars is noticeable near other diffused nebulae, for example, that surrounding *N. G. C.* 6726–7. This condition would be explained if we assume

that stars have not yet been formed by the condensation of this portion of the nebula or that the latter is less distant and slightly opaque.

A similar count was made of ten regions 6′ square, in the vicinity of η Carinae. The plate used was taken with the 24-inch Bruce telescope, and had an exposure of four hours. From this count it appears that in a region 5° square, and represented in Plate 2, described in *Circular No. 15*, the total number of stars was about 250,000, while the number contained on the entire plate exceeded 400,000.

EDWARD C. PICKERING.

March 30, 1897.

Reviews.

ELECTRO-MAGNETIC WAVES.

Joseph Henry in 1842 writing in regard to the oscillatory character of a Leyden jar discharge says: "A remarkable result was obtained in regard to the distance at which induction effects are produced. A single spark about an inch long produced an induction sufficiently powerful to magnetize needles at a distance of 30 feet," and he is "disposed to adopt the hypothesis of an electrical plenum . . . . and it may be further inferred that the diffusion of motion in this case is almost comparable with that of a spark from a flint and steel in the case of light." (*Scientific Writings of Joseph Henry*, I, 203.) Since then, Maxwell, following the ideas obtained from experiment by Faraday, has developed the theory of magnetic action which requires a medium through which electro-magnetic effects are propagated with the velocity of light. Twenty-five years after this theory was published methods of exciting and observing these waves were worked out by Hertz.

Apparatus.—As is well known Hertz excited waves of comparative shortness by the oscillatory discharge between bodies of low capacity and induction. His vibrator consisted of two zinc plates about 40^{cm} square to which were soldered rods ending in brass balls between which the discharge took place. To excite this system the terminals of the secondary of an induction coil are connected to either plate. Succeeding experimenters have not changed the principle of exciting, the only variation being the reduction of the capacity and self induction of the system by diminishing the dimensions. Such a system generates electro-magnetic waves. These waves are propagated through the ether, being composed of an electrical displacement and a magnetic displacement at right angles to each other, both being perpendicular to the line of propagation. For some experiments they may be conveniently guided along wires. E. Lecher (*Wiener Berichte*, p. 340, 1890) describes a method for this which has been much used. Opposite each of the two plates of a Hertz vibrator an equally large plate is arranged and from each plate is led a long wire, the two wires being parallel. The waves are thus guided along these wires, the produc-

tion of waves in these secondary wires being a phenomenon of resonance.

To detect the waves excited in the ether Hertz used a ring of wire in which a spark gap was inserted. When placed in certain positions relative to the vibrating system surgings were set up in the ring and minute sparks appeared at the spark gap. He called this a resonator, because the sparks were strongest when the natural period of the ring was the same as that of the vibrator. In order to obtain a linear detector the ring resonator has been replaced by two linear resonators, placed along a straight line with the spark gap between the adjacent ends. When these experiments are tried on a small scale the sparks are extremely difficult to observe. To overcome this the spark gap has been replaced by a thermal junction, and the throw of a galvanometer caused by the heating of this junction is taken as a measure of the intensity of the surgings. (Klemencie, *Wied. Ann.*, **42**, 416, Lebedew, *Wied. Ann.*, **56**, 1.) This method has been successfully applied to quantitative work in a particularly skillful manner by Lebedew, who has observed waves of a length $\lambda = 0^{cm}.6$ to $0^{cm}.3$.

Rutherford has developed a method which consists of connecting the ends of the resonators to a minute solenoid wound directly on a core composed of a number of fine steel wires. The method of observation is, (1) magnetize the steel wire core to saturation, (2) observe the deflection of a magnetometer needle due to the steel core, (3) connect the solenoid to the ends of the resonator and if surgings be started in the resonator the oscillatory current through the solenoid will tend to demagnetize the core, (4) again observe the deflection of the magnetometer due to the core. The difference between the deflection when the core was saturated and the last deflection is taken as a measure of the electrical radiation. He has only applied it to comparatively long waves. He finds it extremely sensitive, obtaining effects at a distance of one-half mile after the waves had passed through several brick walls and a number of buildings. (*Phil. Trans.*, **189**, 1–24, 1897.)

An entirely different method of detecting these disturbances depends on the change of electrical resistance of a series of metallic bodies in contact when acted on by electro-magnetic waves, commonly called a coherer. (First pointed out by Branly, *Jour. de Phys.*, **4**, 273.) The coherer has been used by Lodge; and more recently Bose has perfected it. (*Proc. R. Soc.*, **59**, 160.)

Reflection.—Hertz found that when electro-magnetic waves were incident normally on a metal surface he could detect points along the normal for maximum and minimum sparking of the resonator. This demonstrated that the phenomenon was of the nature of a wave motion, the observed points being the loops and nodes of the standing waves caused by the interference of the incident and reflected ray (*Wied. Ann.*, **34**, 609). Further it shows that the velocity of propagation is finite. Hertz considered that twice the distance between points of no sparking was the wave-length, but Sarasin and De la Rue have pointed out that this distance depends entirely on the size of the resonator used.

Wave-length.—For Hertz's shortest waves the wave-length $\lambda = 24^{cm}$. By reducing the capacity and self-induction of the vibrator succeeding experimenters have reduced this as low as $\lambda = 0^{cm}.3$ (Lebedew, *Wied. Ann.*, **56**, 1). Waves between the length $\lambda = 0^{cm}.3$ and Langley's longest heat wave, $\lambda = 0^{cm}.0015$ (Keeler, ASTROPHYSICAL JOURNAL, **3**, 63) yet remain to be observed.

Rectilinear propagation.—If the vibrator be placed in the focal line of a cylindrical parabolic mirror and if the laws of reflection are the same as those for light, then the waves from the vibrator will emerge from the mirror as a parallel beam. And if this beam is incident on a similar mirror placed opposite, whose focal line is parallel to the focal line of the first, a linear resonator placed on this focal line will be excited. Further, if a metal screen of size equal to the opening of the mirror be placed directly between the mirror, no effect is produced by the vibrator on the resonator, thus showing approximate rectilinear propagation (*Wied. Ann.*, **36**, 769).

Polarization.—If the waves composing the above beam follow the laws of light waves, the beam emerging from the parabolic mirror is plane polarized. This may be experimentally proved by rotating the receiving mirror and resonator about the ray as an axis. The action in the resonator becomes more and more feeble, and when the focal lines of the two mirrors are at right angles no effect is obtained, the two mirrors acting like polarizer and analyzer. And if the radiation pass a grating of parallel conducting wires only the electrical vibrations perpendicular to the wires will be transmitted, and the ray is plane polarized. By using two such gratings and crossing the wires at different angles, circular and elliptical polarization may be produced.

The question as to whether the electrical or magnetic displacement

is perpendicular to the plane of polarization has been investigated by Trouton (*Nature*, 39, 172). When a polarized beam is incident on a non-conducting surface at the polarizing angle, $\tan^{-1}\mu$, he found that if the electrical displacement is in the plane of incidence none of the radiation is reflected, if the magnetic displacement is in the plane of incidence a portion of the radiation is reflected. Therefore, in a plane polarized beam the electrical vibration is perpendicular to the plane of polarization. The disturbance considered by Fresnel is the electrical displacement, while that of Mac Cullagh is the magnetic displacement; and Maxwell's theory that the magnetic force is in the plane of polarization is verified.

Refraction of the beam takes place when passing from one insulating medium to another. Hertz showed this by observing the change in direction of the beam caused by a large pitch prism and thus calculated the index of refraction. A large number of measurements of indices of refraction have since been made by this and other methods. Bose points out that an excellent way to determine the index is to observe the angle of total reflection (*Proc. R. Soc.*, 59, 160).

Double refraction was demonstrated by Righi (*Mem. R. Accad. delle Scienze, Bologna* (4), 4, 487; *Wied. Ann.*, 55, 389) and simultaneously by Mack (*Wied. Ann.*, 54, 342). If the mirrors be set with their focal lines at right angles, in general the resonator is not excited. But if a block of wood be placed between them so that the grain is perpendicular to the line of propagation of the ray and at 45° to the focal lines of the mirrors, the resonator will be excited, due to what may be called double refraction by the wood. Lebedew has investigated double refraction in crystals and carried the analogy to optics so far as to construct Nicol prisms and $\frac{1}{4}\lambda$ plates (*Wied. Ann.*, 56, 1). Bose noted that the absorption was greater when the electrical vibrations are parallel to the fibrous direction in the crystal and least when perpendicular to the fiber. Bose had measurements made of the conductivity in the two directions and concludes that the absorption in various directions is proportional to the conductivity in these directions (*Proc. R. Soc.*, 60, 433).

Interference of electro-magnetic waves in air was observed by Hertz in his original experiments on reflection. A recent application of interference is that of Bose (*Proc. R. Soc.*, 60, 167) for obtaining a *pure spectrum of electric radiation* by means of diffraction gratings; the gratings being formed by strips of foil. The spectrum found appears well

defined, linear and not continuous. By this method the wave-length may be accurately determined. Interference has been of particular value in studying the propagation of the waves along a resonating system of parallel wires, as described by Lecher (*Wiener Berichte*, p. 340, 1890). If a rarefied tube be placed between the ends of the wires, it will glow, on account of the electrical oscillation in the wires. If the parallel wires be connected by a cross wire, the luminosity in general ceases. If the wire bridge be moved back and forth along the wires some sharply defined positions of the bridge are found which cause the tube to become luminous; and from a knowledge of these positions and the lengths of the wires the wave-length is determined.

Barton, with an electrometer to detect the nodes and loops, has investigated the effect of replacing a portion of the parallel wires by conductors with a capacity per unit length different from the original wires. He considers, (1) the partial reflection at the beginning of the abnormal part, (2) the partial reflection at the end of the abnormal part, (3) the interference between the two sets of waves thus reflected. He finds that as the length of the abnormal part is increased the total energy of the reflected wave is periodically increased and decreased. Thus the experiment is parallel to the optical phenomenon of *Newton's Rings*, the abnormal part of the wire corresponding to the air film. (Final paper, *Proc. R. Soc.*, 57, 68.) In such experiments as the last the reflection of waves from the ends of the wires is troublesome. Barton describes a method for overcoming this (*Phil. Mag.*, 43, 39).

Dispersion.—Garbasso and Aschkinass (*Wied. Ann.*, 53, 534) constructed a prism inclosed in which were a number of tinfoil strips to act as resonators, the strips being all of the same dimensions. On passing the usual parallel beam of wave through this prism, and examining the transmitted wave by resonators of different periods they appear to find dispersion into a sort of spectrum. If this experiment be correct it supports Helmholtz's theory of dispersion. Garbasso and Aschkinass think it shows that the simple two-sphere generator gives waves of various periods which are refracted at different angles. This is contrary to theory and to the experiment of Bose with diffraction gratings. (*Proc. R. Soc.*, 60, 167.)

Drude, while working on dispersion, found that waves 10^{cm} long are much more strongly damped in alcohol and especially in glycerine than in water or aqueous salt solutions. Theoretically the damping should increase with the conductivity, but the badly conducting liquids

are found to damp electrical waves as much as a 5 per cent. solution of copper sulphate, which is some thousand times better conductor. That is, alcohol and glycerine give absorption bands for waves of 10^{cm} length, which would indicate, according to the common theory of absorption, that the molecules of these compounds have a free period corresponding to a period of a 10^{cm} wave. In this same investigation Drude further notes that glycerine and alcohol show anomalous dispersion for waves of about the above length. (*Wied. Ann.*, **58**, 1.)

Relations of K and μ.—A result of Maxwell's electro-magnetic theory of light is that the square of the index of refraction is equal to the specific inductive capacity of the substance. For some permanent gases, liquid hydrocarbon, sulphur, and paraffin, the relation approximately holds, but in general K, the specific inductive capacity, as measured in a slowly varying field, is greater than μ^2. J. J. Thompson (*Proc. R. Soc.*, **46**, 292) and Blondlot (*C. R.*, **112**, 1058, 1891) find that if the specific inductive capacity be determined for electrical waves of high frequency the value of K decreases as the period of the waves becomes shorter. They therefore consider it probable that if K could be measured for waves of the same length as those used to determine the index of refraction the above relations would more nearly hold. On the other hand, E. Lecher (*Phil. Mag.*, **31**, 172) finds that the value of K increases as the period decreases.

Velocity.—Another conclusion from Maxwell's theory is that the velocity of electro-magnetic waves guided by a wire is equal to their velocity in air, this velocity being identical with the velocity of light.

By observing the lengths of the standing waves in a secondary circuit tuned to resonance with the vibrator, and calculating the period of the vibrator from Lord Kelvin's formula for the period of a condenser discharge, $T = 2\pi\sqrt{LC}$, E. Lecher obtained a value for the velocity along wires within about 2 per cent. of the velocity of light (*Wiener Berichte*, p. 340, 1890). Sarasin and De la Rue have demonstrated that the velocity along wires is the same as that in air (*Arch. de Genève*, **29**, 358, 441, 1893, extract of same, *Nat.*, **48**, 252). The same investigators, by observing the nodes in the stationary waves obtained by reflection from a large metallic mirror, and using the calculated period of the vibrator, find the velocity in air to be approximately the velocity of light (*Phys. Gesell. Berlin*, Jan. 6, 1893, extract in *Nat.*, **47**, 336). Blondlot, still using the calculated period and thus making the result not yet independent of theory, found $v = 2.976$

$\times 10^{10\,\mathrm{cm}}$ per second (*C. R.*, 113, 628, 1891). From the same experiment $v = 3.028 \times 10^{10\,\mathrm{cm}}$ per second with the period as recalculated by Mascart (*C. R.*, 118, 277, 1894). By actually observing the time required for a discharge to travel a wire 1029^{m} long Blondlot found $v = 2.964 \times 10^{10\,\mathrm{cm}}$ per second. Another experiment over 1821^{m} wire gave $2.980 \times 10^{10\,\mathrm{cm}}$ per second. His method for observing the time of propagation was to photograph by a rotating mirror a spark through a short circuit and also the spark which had traversed the measured wire. As both sparks were caused by the same condenser discharge the interval of time between the two measures the time required by the second spark to traverse the wire (*C. R.*, 117, 543, 1893).

Trowbridge and Duane also used a method for determining v depending on the principle of resonance. A primary oscillator and secondary circuit were tuned to resonance, and the nodes and loops of the stationary waves set up in the secondary were measured by means of a bolometer. The period was obtained by photographing the secondary spark after reflection from a rotating mirror. Thus, knowing wavelength and period, v is directly calculated. They found for v, $2.816 \times 10^{10\,\mathrm{cm}}$ per second (*Am. Jour. Sci.*, 49, 297, April 1895), and later after some improvements, $v = 3.0024 \times 10^{10\,\mathrm{cm}}$ (*Am. Jour. Sci.*, 50, 104, August 1895). By a similar method Saunders obtains as the most probable result $v = 2.997 \times 10^{10}$ (*Phys. Rev.*, 4, 81). Thus the velocity of electric propagation is identical with the velocity of light.

(Reference should be made to a book which contains the best systematic account of the subject: "L'Ottica delle Oscillazioni Elettriche," Augusto Righi, Bologna.)

GEO. W. MIXTER.

JOHNS HOPKINS UNIVERSITY.
April 1897.

Elementary Text-book on Physics. By ANTHONY and BRACKETT. Revised by W. F. MAGIE. Wiley & Sons, New York, 1897, pp. 512.

WE HAVE before us a thoroughly modern work — modern in the best sense of the word — embodying the views of the best men of all times, including our ablest contemporaries, a work which is the product of no small amount of experience.

To one who has waded through the disconnected pages of Ganot or Deschanel, impressed mainly by the multiplicity of apparatus

employed in the study of physics, to one who has thus familiarized himself with many methods and has yet to learn good method, the present volume will prove very refreshing.

The subjects treated do not differ essentially from those discussed in the majority of texts. The same may be said of the order of the treatment. As exceptions to the two statements just made may be mentioned nine pages devoted to gravitational potential, a two-page summary of results from Helmholtz's *Memoirs on Vortex Motion*, ten pages given to the simpler mathematics of the kinetic theory of gases, and a couple of pages on Ewing's *Molecular Theory of Magnetism*.

If then it be asked what is the distinguishing feature of the book, the reply is unity of method in treatment. Fields of force and equipotential surfaces are introduced in the discussion of general dynamics; waves are first presented, under the mechanics of fluids, by a summary, perhaps too short, of the work of the Weber brothers. A general treatment of waves is prefixed also to the discussion of sound. The result is that the potential theory and the theory of waves may thereafter be freely used throughout the book. And in general the treatment of sound, heat, light, electricity, and magnetism may be described as dynamical.

This method is by no means exclusively true of the book before us. The altogether excellent *Theory of Physics* by Ames presents in a most admirable manner the unity of the subjects studied under the head of physics.

There are, however, some omissions which we cannot help wishing Professor Magie had seen fit to make. Among these may be cited the *unproved* expression for the amount of twist (angular displacement) produced in a given wire by a given couple (Eq. 47), or Ampère's expression for the action of one current element upon another (Eq. 103). If one of the chief aims of laboratory work be to discourage the all too easily acquired habit of taking things for granted, may it not be wise, in the lecture room, to reduce to a minimum the formulæ which we ask the student to take without proof.

As illustrating what your reviewer considers always desirable may be cited the articles on the "Propagation of Sound," where the student is *not* left with the bare assertion that

$$V=\sqrt{\frac{E}{D}}$$

but is furnished with the rigid proof of Rankine. The same might

have been done in as simple a way (Tait's demonstration) for the speed of transversal disturbances in strings,

$$V=\sqrt{\frac{T}{\mu}}$$

But one does not need to teach physics very long to find that however excellent a text-book may be, considered alone and by itself, it is a matter of no small difficulty for any instructor other than the author to use the book in his class room. It is, therefore, very much to be hoped that, in the near future, universities will be able to employ men who are competent to write their own books, and who prefer to write their own books, and that the universities will make it possible for these men to print their own books. H. C.

Analyse spectrale directe des Minéraux. Par ARNAUD DE GRAMONT. Paris, Boudry et Cie., pp. 207.

THE author of this work having found that certain minerals are sufficiently good conductors to permit an electric spark to be passed between fragments used as electrodes, undertook to establish a system of direct qualitative analysis based upon observations with a small laboratory spectroscope. The method of analysis is simple, and apparently well adapted to the ordinary requirements of the chemical laboratory. A strongly condensed induction spark, taken between fragments of the mineral held in platinum clips, is examined with a direct vision spectroscope containing two compound prisms, giving an angular separation of the D lines amounting to something over 1′. In the violet the absorption of these prisms is so marked that but one of them can be employed. The observing telescope contains a scale of 250 parts, and the measures are made by simply estimating the positions of the lines with reference to the scale divisions. The wave-lengths of the standard lines used in forming the reduction curve are those of Thalén, and all the measures are therefore based upon his results. The author considers his wave-lengths to be reliable to a single Ångström unit. They are consequently better adapted to the purposes of the analytical chemist than to those of the astrophysicist.

M. de Gramont finds that the spectrum of sulphur can be obtained without the aid of a vacuum tube, by simply passing the condensed spark between two points of platinum or carbon which have been

dipped in melted sulphur and allowed to cool. The chlorides give the spectrum of chlorine in addition to that of the metal, and iodine can also be recognized in its compounds. Tables of the wave-lengths of the principal lines in the spectra of nearly one hundred minerals, with accompanying descriptive matter and several plates, complete the volume. G. E. H.

Some Experiments on Helium. By MORRIS W. TRAVERS. *Proc. R. Soc.*, **60**, 449-453, 1897.

THE investigation which forms the subject of this paper directly concerns the evidence in favor of the *mixture* theory of clèveite gas. Upon diffusing the gas through an asbestos plug, Runge and Paschen noticed a change in the relative intensity of the two sets of lines into which they had divided its spectrum. This strengthened the conclusion already drawn, that the gas is a mixture. They stated, however, that this change might have been due to the reduction of pressure, as the latter was lower in the tube containing the diffused gas than in the other. It was subsequently noticed that the gas was absorbed by the platinum deposited on the walls of the tube, and the possibility of separating the supposed constituents by a process of selective absorption suggested itself to Mr. Travers. In his experiments, a tube was filled with clèveite gas under 3^{mm} pressure, and the current turned on, resulting in the following succession of colors in the tube: (1) yellow, slightly red, (2) bright yellow, (3) yellowish green, (4) green, (5) green, with phosphorescence, (6) phosphorescent vacuum; spark between electrodes outside of tube. After testing for vacuum by means of a pump the tube was heated, resulting in the discharge of gas from the platinum, and the succession of the above colors in reversed order This showed that all the gas had been absorbed by the platinum and was given out again under the influences of heat.

The tube was now refilled, run to state (4), and exhausted. Upon reheating we should expect a yellow or a green glow, according as the color change was due to selective absorption of a yellow constituent, or to a reduction of pressure in the tube. The resulting illumination, which was green, therefore seemed to prove it to be due to this latter cause.

The relative absorptions of different gases by the platinum is touched upon in the paper. In particular argon is found to be taken

up very slowly, and may be freed from some of its impurities in this manner.

From all that is contained in the paper there seems to have been no systematic observation of the relative intensities of the spectral lines during the changes described, casual reference to the green line only appearing. In view of the systematic variation in each of the two sets reported by Runge and Paschen, and referred to above, it is to be regretted that the experiments were not extended so as to confirm it. However, the paper is a valuable contribution, and coming as it does when the status of the *mixture* theory is somewhat doubtful, its appearance is most opportune.

W. H. WRIGHT.

YERKES OBSERVATORY,
April 1897.

RECENT PUBLICATIONS.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of the ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors. For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

BACKLUND, O. Beobachtungen der totalen Sonnenfinsterniss auf Nowaja Zemlja am 8 August, 1896. A. N. 143, 17–19, 1897.

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SUBJECTS.

For titles of Reviews see table of contents.

INDEX OF AUTHORS.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. If a request is sent *with the manuscript* twenty-five reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

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